MOLLIER

Study Association
Building Physics and Services

INSIDE INFORMATION

MOLLIER | UNIT BPS | STUDENTS | ACTIVITIES | MEMBERS

Academic year 2025-2026

Fire Loads in Escape Routes: Ensuring Equivalent Fire Safety in Senior Housing

Réka Márta

Comparing Open-Source Room Acoustics Simulation Tools: Performance and Usability Insights

ir. Luc Dijkman

Illustrating the Impact of Wear Position on the Performance of Wearable Light Sensors

ir. S.W. (Sietse) de Vries


MOLLIER
Evelina Felixela
Antwerp Cathedral - 1370's
Antwerp
MDE
19/04/26

Foreword

Dearest reader,

Have you been wondering what has been happening in Mollier for the past year? Look not further! In this edition of the INSide information, we will introduce you to the board that has been running the association this academic year, let you meet all the committees that are working in the background, and give you an overview of all events that have happened. You will also meet some new faces within the association and see what members have been up to abroad.

As you are used to from us, we have also gathered articles that will bridge the gap between our studies and the actual world of building physics. Several students will present the projects they have been working on over the past year, ranging from an analysis of the fire resilience of CLT to a comparison of open-source room acoustics simulation tools. In addition, multiple sponsor companies will give a look into the projects that they have been working on.

I would of course like to extend a big thank you to everyone who helped to make this edition of the INSide Information possible by writing an article. I know as no other how busy schedules can get while studying or working, but contributions like these make it possible for us to publish Mollier's magazine. I would also like to thank Ida, for the support she gave us from the board. Lastly, I would like to give the biggest thank you of all to Yenthe, who has balanced her graduation with all preparations for this magazine like a pro. I couldn't have done this without you!

Now, on to the more interesting pieces of the magazine: sit back and enjoy this edition of the INSide Information!

On behalf of the INSide committee,
Yours sincerely,

Manon Hanssen
Editor-in-chief

INSide Committee
v.l.n.r.: Yenthe Smienk, Manon Hanssen

COLOPHON

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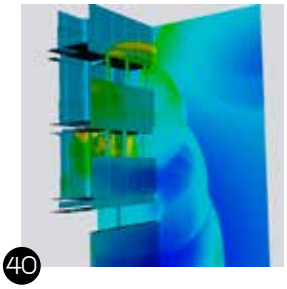

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Introduction to the 30th Board of Mollier

The 30th board of s.v.b.p.s. Mollier was constituted on Friday September 12th, 2025. On this page, they will introduce themselves and answer (some of) these five questions;

1. Coffee or energy drinks during deadlines?
2. What's the most unexpected hobby you have?
3. Which course or topic made you question your life choices the most?
4. If you could instantly master any skill, what would it be?
5. What is your favorite building?

KARLIS ANDERSONS, CHAIRMAN

Hey, chairman of 30th Mollier board over here, my name is Karlis Andersons, I come from this small country (bigger than the Netherlands, with 10 times less people living in it), called Latvia. I am 9+10 years old. The high-level education, international environment, and my love towards physics were the main reasons why I came to Eindhoven University of Technology. Originally, I came here to study structural engineering, but right now I am a third year BPS bachelor's student, this decision was based on the most important economics rule: supply and demand.

Being a BPS patriot and understanding the importance of the quantity and quality of BPS graduates, I decided to join Mollier to help stimulate this community. I hope to work together with the 30th board of Mollier and motivate the BPS students to have fun and widen their knowledge and network with local companies. Despite being only halfway through our board year, we have had lots of events and even more fun, but the highlight is definitely Tour De Bar, which is our most successful event. The people who were there know what I am talking about!

1. I am not the biggest coffee and energy drink enjoyer, but I like couple of sips of "what's new in the fridge" and a mouth full of "doom scroll".
2. My favorite hobby is crying about having no time, and ice hockey.
3. ITEC courses just get on my nerves.
4. I want to learn the skill of cleaning the kitchen before Ratatouille offers a helping hand.
5. My favorite building is the ice-cold Eindhoven Ijssportcentrum.

ANDREAS HEHN, SECRETARY

Hey there, my name is Andreas, and I am the Secretary and Vice-Chairman of the 30th Board of Mollier. I'm currently in the third and final year of my bachelor's, following the Building Physics and Services track. As Secretary, I am responsible for communication and administration within the board, making sure that everything runs smoothly and doesn't descend into chaos.

I've been fascinated by physics and innovation for a long time, but my real passion has always been architecture, which is why Building Physics turned out to be the perfect fit for me.

Upon realizing how few share these interests, I decided to join the board to help show that BPS is far more interesting and fun than people might think.

As board, this year I hope to make the association and BPS as a track more popular, especially among the bachelor's students, but also to maintain the close ties to all the current and past members.

My favourite Mollier memory so far is probably our constitutional drink. There was a lot of preparation put into it, and so many have showed up in the end. It was a great way to kick off this board year.

1. I usually rely on coffee during deadlines. The situation needs to be very dire when energy drinks come into the picture.
2. I used to make models of war vehicles, mostly airplanes. It's quite busy now and all my tools are back home, so I haven't done it for a while.
3. Multi CBL probably. After forgetting to submit a topic preference, I ended up working on improving digital literacy for a South African neighbourhood. Not something I expected to do when I applied for this program.
4. While reading minds is impossible, understanding body language is the closest thing that can actually be learned. It's I think one of the most useful things one can learn.
5. I really like the pantheon in Rome. It's marvellous both architecturally and from an engineering point of view.

MACIEJ PAWLAK, TREASURER

Hey there, my name is Maciej, and I am the treasurer of Mollier for this year. I am in my second year of bachelor's as a BPS student.

As a treasurer, I will do almost everything money related. I am here to make sure we don't run out of money while creating all the activities for you. On top of that, I am the board member responsible for the fun committee.

I joined the Mollier board because throughout the first year, I felt like not enough focus was put onto Building Physics and I happen to like it a lot. So, I wanted to help Mollier and Building Physics become more mainstream in the Built Environment.

1. Definitely energy drinks, I can't stand the taste of coffee.
2. I'm quite interested in the history of presidents of the United States, so probably that.
3. I didn't have many courses so far, so probably Systems in the city, just a very boring course that I really did not enjoy studying.
4. Football, easily, something I really enjoy and would love to be able to do it at the highest level.
5. Maison de Jean Prouvé, nothing else comes to mind, and the Maison Prouvé is the building that I found interesting enough to make me want to study BPS.

IDA KEULEN, COMMISSIONER OF EXTERNAL RELATIONS AND PROMOTION

Hi my name is Ida and this year I will be the commissioner of external relations and promotion. I'm 24 years old and I come from the south of the Netherlands.

I came to Eindhoven to study Architecture, Urbanism and Building Sciences in 2020. After pursuing architecture and urbanism in the bachelor's, I chose the Building Physics track for my Master, as it is more factual and not as vibe-dependent as architecture.

This is my second year being a Mollier board member. I decided to stay another year to guide the four new board members and help with continuing and renewing the Mollier cycle. I hope the association will get a fresh new board next year and continue the work we have put in for the past two years to build the Mollier community up again.

My favorite Mollier memory is the past Schoone Leij borrel, I felt really connected to my fellow students and saw how engaged Mollier members still are decades after graduating, I would like to stay in touch like that too.

1. Coffee, I don't like the taste of energy drinks. But when times are really rough, an energy drink is sometimes needed.
2. I seem pretty shy, but every Sunday, I smash some women on a grass field during a game of Rugby.
3. CFD, why is it so theoretical?
4. I would like to be able to speak a lot of different languages.
5. I really enjoyed visiting the Sagrada Familia in Barcelona.

SAHRA GHODOUSI, COMMISSIONER OF EXTERNAL RELATIONS

Hi, I'm Sahra, Commissioner of External Relations (and yes, I will probably talk to you about coffee at some point).

I'm from Iran, and I came to Eindhoven to study Building Physics and Services after realizing something slightly uncomfortable: as an Interior Architecture graduate, I was designing spaces that looked good; but I didn't fully understand how they truly support user comfort. The crisis started with lighting design and quickly escalated into questioning everything about energy, performance, and the details behind it. So here I am.

I chose BPS because I wanted to bridge that gap between design and technical performance. I don't just want spaces to look good. I want them to feel right and perform well and not waste energy.

During my first year, I noticed something missing: more connection to how things actually work in practice, and more genuinely fun moments with people going through the same struggles. University can be intense, and I felt it could be a lot more engaging than just deadlines and simulations. That's where Mollier comes in. It creates the kind of environment I was looking for; social, useful, and a bit more alive. I naturally enjoy the behind-the-scenes part of that—organizing, coordinating, and making sure everything (and everyone) connects smoothly.

Joining the board felt like the natural next step. As Commissioner of External Relations, I want to bring companies to the world students inhabit: less stiff networking events, more real opportunities and meaningful connections. My goal is to make these interactions both useful and enjoyable.

1. Coffee is not a preference; it's the daily dose of joy.

EGOR SERGIENKO, COMMISSIONER OF EDUCATION

Hello everybody, my name is Egor, and I am doing a second board year as the Commissioner of Education of Mollier.

I am in my second year of the Building Physics and Services Master. I am 25 years old and I come all the way from Novosibirisk, which is the 'capital' of Siberia. Specifically, I come from Akademgorodok, which is one of the main academic towns in Russia. I came to Eindhoven to study buildings and built environment, because it seems that the Dutch people have figured those out really well. I did so all the way back in peak covid times, which was 2020. Starting my bachelor's, I have realized very quickly that I am very interested in all things physics in buildings, and especially performance assessment and optimization of building, so I have chosen for BPS track straight away.

This is my second term in the Mollier board. I have decided to stay as I had some ideas about doing study related workshops and wanted to participate in the master revamp process that is ongoing within the university.

This year I am hoping to help the faculty to increase the quality of course materials and lectures, as well as organize some workshops and make sure these are recurring in the next academic years.

My favourite Mollier memory? Being woken up by a person whom I don't know in a place I do not remember coming to, after my first constitution borrel.

1. I would say both, but even though energy drinks are tasty, I do not feel the urge to have a heart attack at 30 at the current moment, so coffee will have to do.
2. Even though I am Russian, I play Spanish music, which you can call unexpected, as I didn't really envision doing that when coming to study here. Thus, it is a thing that also makes me question my life choices, because so far playing 'unexpected' Spanish music has brought me more money and experience than all my other activities during the past years. Mastering Spanish instantly? Si!
5. Here you might think I would say something about Spain again, but no, it is the Melnikov's House in Moscow! The promise of constructivism and new way of living, before the Soviets decided that people have to live in depressive concrete boxes.

Mollier Committees

A study association is nothing without its committees. Active members make the association go round. Take a look at the committees Mollier has to offer, do you find something you would like to do?

INTRO ACTIVITY / MDE COMMITTEE

Do you want to organize a start activity to start the year, and bring the BPS students closer together on a city trip? Then the start activity committee could be your call. You get a budget from the treasurer with which you may do what you like to ensure a fun weekend (Multi Day Excursion) for Mollier students to get to know each other at the start of the year. The MDE is a fun weekend balancing educational excursions with cultural excursions and student life in another city.

BEER TASTING / WINE TASTING / FUN ACTIVITY COMMITTEE

Do you like alcoholic beverages? And do you have a fine taste in sorting out the best wines or beers to present to your fellow students? Then, join the Wine or Beer tasting committee (or make it a cocktail party committee) to organize one evening on campus to provide for our thirsty members and get to know eachother in a more casual setting. The wine and beer tasting activities fall under our fun activities, but if you have any other idea for a fun activity that you would like to organize for Mollier members, reach out to the board!

INSIDE INFORMATION COMMITTEE

Do you like to gather information from students, professors, alumni, and sponsors? Do you like working with Adobe and letting your creative side speak to make such a wonderful magazine like the one you are reading right now? Join the INSide Information committee to ensure the spread of BPS-related information. We are looking for the next generation of editors-in-chief and creative directors to make sure the magazine is being continued. Again, you are in contact with companies, teachers and students, broadening your network and enhancing your skills in communication, planning, collaboration, and editing.

MEET&GREET COMMITTEE

Each year Mollier organizes a Meet 'n' Greet activity, where you can come and talk with our sponsors, who are BPS companies. You can learn about career opportunities and have a casual chat with the people who went before you. Do you want to help organize this amazing event? The main tasks are reserving the location, inviting the companies, making the program and set up the tables and food and drinks. Contact the board if you want to boost your network and join the committee!

STUDY TRIP COMMITTEE

Study trip in one of the yearly events, that has not been so yearly recently, where a group of students travels to a different country to learn from worldwide companies and their experts, broaden their view on the world, and, of course, get some rest from the daily routine. The planning of this trip took a lot of effort. Thankfully, there are a lot of motivated BPS students because, as we all know, teamwork makes the dream work.

The committee started off with 5 members; Karlis, Clara, Teun, Nina and Merve, and without wasting time, already at the very start of the year we got right down to business. We wanted to utilize the depth of the committee, so we took every task very seriously. We decided up on 5 destinations, and each of us had to make a presentation about why we should organize a study trip to their respective country. Out of Japan, Brazil, Turkey, Iceland, and China, Japan got chosen as the most appropriate destination due to the extraordinary culture, advanced engineering, good weather, and amazing food.

Unfortunately, by the time we reached the detailed planning phase, our committee had shrinked to 3 members. But that did not stop us because we were coming in hot into the next phase of the trip planning. Now that we knew that we are going to Japan, it was time to manipulate our Instagram algorithm to show us only videos about Japan, because we all know that social media is the best tour guide agency. We started with more general research about Japan and the cities that could be interesting to visit, and the list was endless. We had to cut down to manageable amount of destination. After figuring out which areas of Japan we want to explore we started the creation of a detailed plan. We will visit Tokyo, Nikko, Kyoto, and Nara.

Follow us on Instagram to see our Japan vlog and stay tuned for the next edition of this magazine for the detailed study trip recap!

Study Association
Building Physics and Services

Mollier Activities 2025-2026

GMM #1 + COBO 12 SEPTEMBER 2025

In Q1, we constituted the 30th board and organized our CoBo, followed by the traditional CoBo dinner with members and alumni. The new board consists of six people and they presented a fresh vision for the upcoming year! Everyone survived the CoBo and made it to the restaurant l'Azzurro for a nice meal!

TOSTI WEEK Q1, Q2, Q3, Q4

To kick-off the year, and engage the new BPS student with Mollier and our place in the Hok, we offered free tosti's for a week. This really helped getting to know the BPS students and promote ourselves and the upcoming activities. This was such a success that the board decided to do it at the beginning of every quartile.

PYTHON WORKSHOPS

Our Commissioner of Education, Egor Sergienko, organized four Python workshops to support students in the master course "Intelligent Buildings", where building data is analyzed. The workshops were also complemented with free pizza!

MEET THE BOARD DINNER 19 SEPTEMBER 2025

On Friday 19 September, we hosted another dinner, taking place at the Radegast, to get to know the board and welcome our new Mollier members. It was a fun evening of catching up and discussing our plans for the upcoming academic year.

TOUR DE BAR 20 SEPTEMBER 2025

You just had to be there... We went past all the nice bars Eindhoven has to offer. Cycling became more difficult towards the end of the evening, but luckily, no one was (severely) harmed.

LUNCH LECTURES

In Q1, Kompas had the honor to give the first lunch lecture of the year. Furthermore, we organized three Lunch Lectures in Q2. Many thanks to Sweco, SPIE Nederland, and Actiflow BV for their engaging and insightful talks. In Q3 we welcomed Nelissen, Haskoning and DGMR to educate the students on the BPS working field.
After the Actiflow lunch lecture, the locations of the MDE and Study Trip were revealed; we are going to Antwerpen and Japan! In Q4 lectures by Cauberg Huygen, ABT and LBP Sight were planned.

AFTER EXAM DRINK 6 NOVEMBER 2025

After the first exam weeks of the year, Mollier brought the SkyCard down to the SkyBar to treat everyone on a well-deserved drink.

RICHARD'S BIRTHDAY DRINK 27 NOVEMBER 2025

To celebrate the birthday of our founding father Richard Mollier, we went to Meteor community café to toast on his 162nd birthday.

BEER TASTING 9 DECEMBER 2025

The annual beer tasting took place in the Skybar again, thanks to Benedek Plander for organizing this! He carefully selected a number of beers for the students to try, which we tasted paired with complementary snacks! With use of a little quiz about each beer, we learned something new about each beer while tasting it

DE CAAI EXCURSION 28 JANUARY 2026

On a Wednesday during the Q2 exams, Mollier paid a visit to the canalside of Eindhoven. Where once stood the most modern Dairy factory of the Netherlands, owned by Campina, is now the site of a large redevelopment project tying the monumental factory buildings together with modern mixed-use towers while keeping the history of the site into account. The area close to the water offers a good potential for a blue and green corridor in the city of Eindhoven. We were welcomed in the Bottle Distillery, where René Claessen from Kompas presented the plan together with the developer BPD. They explained the timeline from gathering the land by winning a tender, placemaking by temporary initiatives like 'StadsOase' and building the buildings to eventually selling the apartments. After the presentation we got to walk around the cramped site to see the buildings in construction. It was interesting to see a construction site up close, thanks to Kompas for organising this!




SCHOONE LEIJ DINNER+DRINKS 6 FEBRUARY 2026

On Friday February 6th, the Schoone Leij, our Mollier Alumni association, invited us to gather in café de Wildeman for the first SL borrel of 2026! During these gatherings, old Mollier members come together to catch up, and current students join them to enjoy some cheap food and drinks and make some connections to people working in the BPS workfield. It is always a pleasure meeting eachother again!

GMM #2 11 FEBRUARY 2026

During the intermediate GMM the Mollier Anthem was sung and updates on the past half year regarding the board view, sponsors and finances, members and activities were given. It was a brief meeting where, within an hour, our members were being informed of all actualities concerning the association.

MOLLIER COMPANY DINNER 6 MARCH 2026

On Friday March 6th, eighteen Mollier students and eight employees of five different sponsors of Mollier gathered at café Centraal. During the company dinner, employees from Kompas, Sweco, Haskoning, Klictet, and DGMR got the opportunity to talk to the students of Mollier and vice-versa. During the three- course meal and unlimited drinks, tables got switched so everyone got to talk with everyone. Whether it was a first year bachelor student orientating themselves, or a recent graduate looking for a job, everyone was there and welcome. It was a great success and we hope to organize another company dinner soon.



BBD CAREER MARKET 11 & 12 MARCH 2026

This year the annual career market organized by the BouwkundeBedrijvenDagen took place over two days! Mollier had their own stand and guided two tours along the companies related to BPS on the market. It was a great opportunity to explore the options for during and after your studies!

BOARD GAME EVENING 27 MARCH 2026

Our dedicated Mollier members Manon and Theun organized a board game evening in Joto's board game café on Strijp-S. The board game night was amazing! Not often do you get to play games with a large group, so this was a real treat! It's a great way to get to know each other!



INHOUSEDAY SWECO 2 APRIL 2026

On April 2, we were invited to the Sweco office in Eindhoven. After a brief presentation by Nadjeche about the company, Farima and Marieke, both consultants at Sweco, divided the fifteen students into three groups and launched the challenge with a brief quiz. After the quiz, they gave the students a case about making the building of Ikea in Eindhoven more energy efficient and comfortable. The three teams became equipped with floorplans, details about the structure and insulation values, occupation, installations, and energy assessment. Two hours, interrupted by a 'fika', of brainstorming and teamwork later, the groups had to pitch their proposed improvement measures. The general consensus was that daylight and energy used by artificial lighting was the most important part where energy could be saved. After the pitches, the students went to enjoy some drinks and snacks while the jury evaluated the pitches. After all, team BEST won by their implementation of a SWOT analysis and thinking about the implications of the measures on the activity of the building.




MDE TO ANTWERP 17-19 APRIL 2026
Read more about the MDE on page 38!

MEETANDGREET XL 23 APRIL 2026
On April 23rd, the annual Meet & Greet returned with an exciting "XL" twist. Designed to move away from standard corporate pitches and dive straight into the realities of the field, this edition brought together students and industry professionals for an afternoon of technical sharing and networking.

The day kicked off with a walk-in lunch in the Trappenzaal. It was a great opportunity for students and company representatives to catch up over coffee and tea before the main program began.

Once everyone settled in, the afternoon transitioned into the technical deep-dives. Presenters from Haskoning, Actiflow, and Cauberg Huygen took the stage, opening up their playbooks to show students the "nitty-gritty" of their projects. Instead of generic company overviews, the audience was treated to real-world workflows, the actual software and tools used in the office, and the step-by-step logic required to solve complex, messy challenges in professional practice. Later, the networking session opened in the Vertigo Cafeteria. Students had the chance to have genuine, face-to-face conversations with our guests from 9 companies that are Mollier sponsors.

To wrap up the event, everyone gathered for drinks, snacks, and a live Pop Quiz. The questions tested the audience on the technical details shared during the earlier presentations, alongside some general BPS knowledge. It was a fun, competitive way to see what everyone had learned throughout the day, culminating in a well-deserved prize for the sharpest student in the room.

Until the next edition!

BOARD INTEREST DINNER 30 APRIL 2026
To spoil the candidate board and convince them to actually become the next board of Mollier, we invited everyone that was interested to Grand Café de Lichttoren for a nice meal and talk about being board. For those who missed it, check out the introduction to the board article to see what board roles there are!

STUDY TRIP ICE BREAKER 13 MAY 2026

The group chemistry is very important for the study trip to be successful, that is why we organized an event where all the members could get to know each other better. We started with a small presentation where we painted the picture on how the trip could look like. Before going to Japan we had to make sure that everyone knows how to use chopsticks, so we made a small challenge where the participants had to collect as many dry beans as possible. The winner got a free drink in Hubble. After the event the members became better friends and the vibe was way more relaxed.

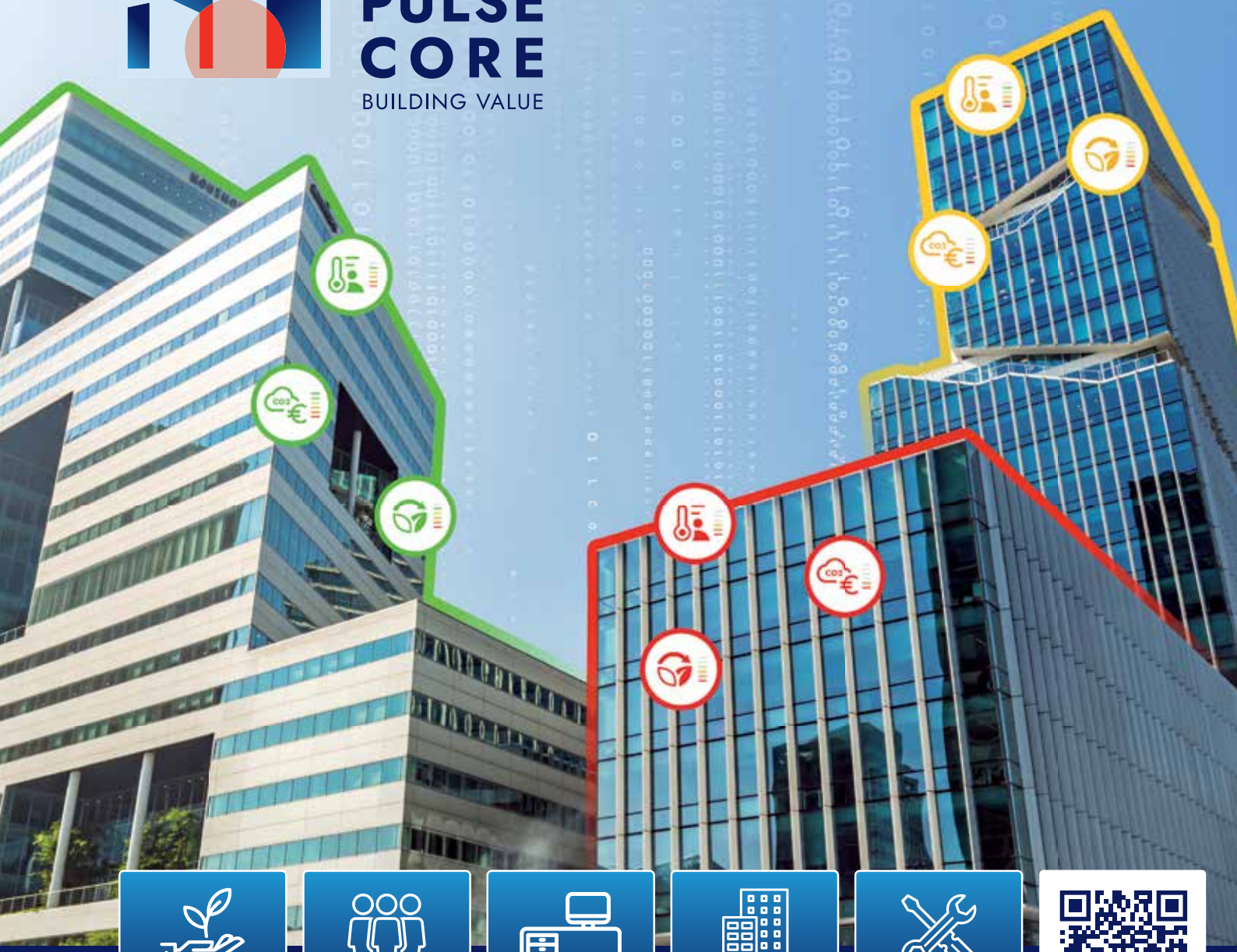
WINE TASTING 20 MAY 2026

The annual wine tasting took place in the Proteus pavillion at the edge of the campus. The dear committee picked out six wines from the mediterranean area to give us a holiday experience in a glass. Paired with snacks and music, the vibes were totally complete. The wine tasting, being one of our most attended events (guess why), was a great success! This time, instead of being snobbish about the taste of wine, we went the direction of looking at history and having a great deal of conversation. Starting with the Georgian wine, which was the absolute favourite of everyone, also recommended to you, the mood was set. Continuing through history, and the mediterranean countries, we have tasted many wines, out which, the French one came out to be the worst. That was expected, I mean, there is a reason why French farmers stop the trucks carrying Spanish wine. Because theirs is non competitive. Simple. However, even those bottles helped the conversation to flow, so great thanks to the all wine makers who make such a beautiful drink. And thanks to the people who helped organize the event!

UPCOMING ACTIVITIES:

Sexy section party	27 May 2026
Lunch lecture Cauberg Huygen	28 May 2026
Lunch lecture ABT	4 June 2026
BPS Student Day 2 + INSide Information reveal	11 June 2026
Lunch lecture LBP Sight	18 June 2026
Active member activity	t.b.d.
Study trip to Japan	5 July-17 July 2026

PULSE CORE
BUILDING VALUE



Sustainability | Comfort | Workspace | Assets | Operation

SCAN ME!

Proud professionals making buildings more valuable.

Carbonated Recycled Concrete Fines in LC³ Binder and Zero-Slump Concrete

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INTRODUCTION

Concrete is widely used in the built environment and in civil engineering. Its main components are inert aggregates and cement. Both components have their characteristic issues regarding sustainability and recycling potential. On the one hand, aggregates are voluminous and in demand in large quantities, which leads to rapid degradation of natural landscapes through extraction of the materials. On the other hand, the production of clinker cement releases large quantities of CO_2 per tonne produced due to both the demand for fuel and the chemical process of heating calcium carbonates ($CaCO_3$ + heat → $CaO + CO_2$) [1].

Current strategies to combat the negative side effects of concrete production involve reducing the clinker demand by finding alternative cementitious materials. When cement hydration takes place, hard crystalline materials are formed, which provide strength. Research over the decades has found certain materials that can aid in the forming of these crystalline materials, for example limestone powder, clay or fly ash. These materials are referred to as supplementary cementitious materials (SCMs) and are usually less CO_2-intensive to obtain. So, these materials can replace part of the clinker cement while maintaining the strength. One example of a blend of materials is called LC³ [2], which is a ternary blend of limestone, calcined clay and clinker (see fig. 1). Upon hydration, the calcareous limestone (which is 99% $CaCO_3$) and calcined clay have additional reactions, producing more crystalline materials (e.g., carboaluminates). A clinker reduction of 50% can be achieved while maintaining strength. This is a very promising development in the cement industry.

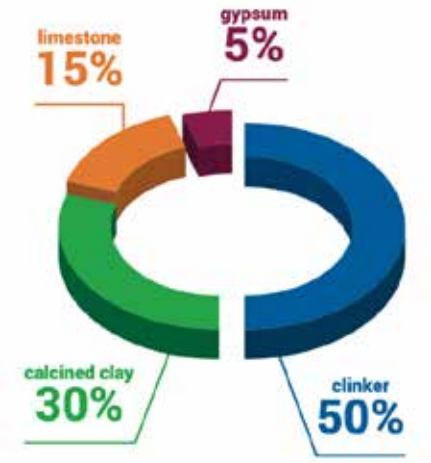

Figure 2. Composition of LC³ binder [3]

The demolition of buildings produces recycled concrete (RC), which gets industrially crushed and sorted into size fractions. As a commodity, it has a limited number of uses: current concrete production can include up to 20wt.% RC without affecting the strength too much; RC is also used as road base or sound barrier material. However, the supply of RC exceeds the demand, and therefore it is sensible to find additional uses.

Reusing RC as fine aggregate in new concrete appears to be a logical solution; RC consists for the larger part of old aggregates, and is widely available. Simply treating RC as natural fine aggregates comes with a few limitations, however. RC is a mix of inert aggregate with adhered hydrated cement paste, making the material difficult to characterise. Both natural aggregates (NA) and RC have inert quartz (SiO_2), but RC also has hydrated cement remains (C-S-H and portlandite). These cement remains are porous and mechanically weak, and have higher water absorption than NA [4]. This makes them inferior to NA. Additionally, research shows the quantity of unreacted cement remaining in RC is not enough to offset its negative qualities [5].

To prepare RC for reuse, it is usually separated into size fractions. Smaller particles tend to contain relatively large amounts of hardened cement paste, instead of inert aggregates [6]. The distinction between these fractions is not consistently defined in the literature. The terms RCA, RCF, and RCP (referring to recycled concrete aggregate, recycled concrete fines, and recycled concrete powder, respectively) are widely used; however, the particle size boundaries delineating each fraction vary considerably and are often dependent on the specific methodology and scope of the study in question. In this study RCF refers to RC sized 0 – 2.0mm, and RCP refers to a sub-fraction of RCF, namely 0 – 0.063mm.

Carbonation of RCF is an effective method to reduce these negative

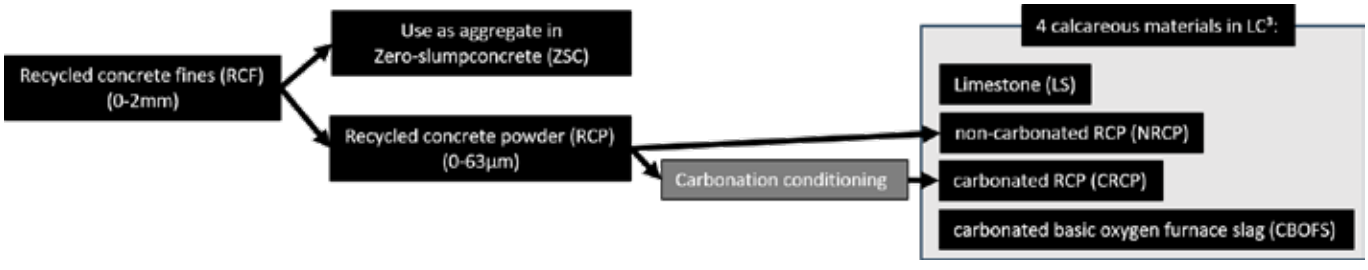

Figure 2. Methodology

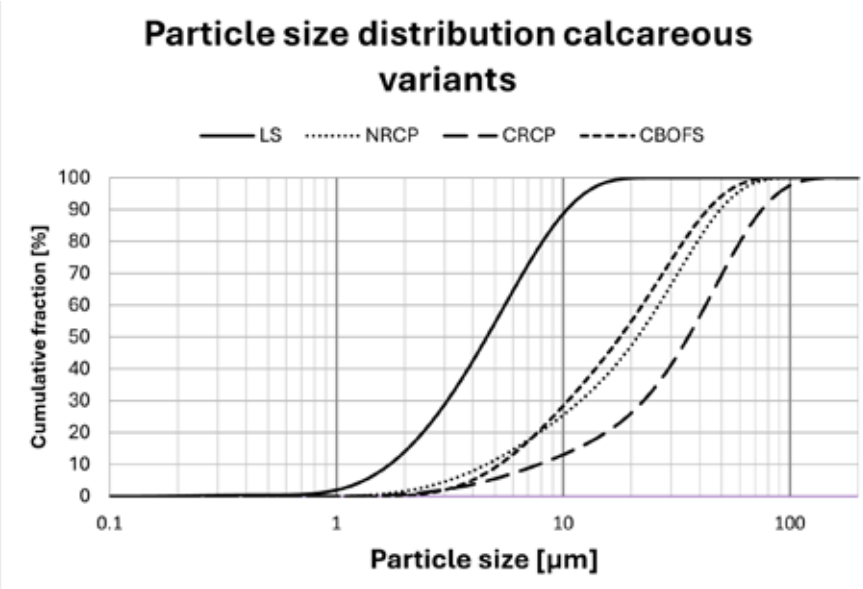

Figure 3. Particle size distribution of the calcareous variants used in the LC³ binder

properties [7]. Carbonation is the process of forming calcium carbonates ($CaCO_3$) by letting CO_2 react with hardened cement. This process occurs naturally, as the atmospheric CO_2 concentration is approximately 5%. Accelerated carbonation is done in controlled environments, such as climate chambers, and can reach much higher concentrations. Calcium carbonate forms in the pores of the hardened cement to reduce porosity and increase the volume. Accelerated carbonation is a proven treatment method to mitigate the negative properties of RCF, making them into a more attractive material as 1) supplementary cementitious material, and 2) replacement for natural aggregate. Cement hydration products from previous hydration (e.g., calcium oxide) is converted into calcium carbonate ($CaCO_3$), which precipitates in the pores of the RCF.

RESEARCH OBJECTIVE

This research deals with the recycling of RCF by exploring two distinct potential uses. Firstly, using carbonated recycled concrete powder as source of calcium carbonate to replace limestone in LC³ is researched. The aim is to reduce the demand for quarried limestone and find additional uses for RCF. Secondly, the effectiveness of carbonation directly after unmoulding of concrete samples is researched (fig 2). So-called zero-slump concrete (ZSC) can produce cylindrical samples, which have no visible slump after demoulding. Such samples can be carbon-cured in a carbonation chamber to possibly enhance their strength. Additionally, the influence of RCF particle size is also studied. All this should present a case of new possible uses for RCF.

METHOD – LC³ MORTAR

The RCF was sieved into fractions to produce recycled concrete powder which was characterised to determine its carbonation potential, and detect any eventual contaminations. By performing a particle size analysis, X-ray diffraction- and fluorescence, and thermogravitational analysis, the elemental composition and phase assemblage of RCF was determined.

The smallest fraction of RCF was made with the finest sieve available: 63µm. The fraction of 0-63µm was used as supplementary cementitious material, and is referred to as recycled concrete powder (RCP). LC³ binder blends were designed to research the effects of replacing limestone (LS) with RCP, both carbonated and non-carbonated (CRCP and NRCP, respectively). Additionally, carbonated basic oxygen furnace slag (CBOFS) was included as replacement material, due to calcareous properties and availability from previous research.

The four binder variants were used in mortar with a ratio of 1 part binder to 3 parts natural sand by weight. The resulting mortar was tested for ultrasound and shrinkage (7 days) and used to cast prism-shaped samples, which were subsequently tested for flexural- and compressive strength.

RESULTS AND DISCUSSION – LC³ MORTAR

It was found that the particle sizes for the four calcareous components in the LC³ binder (Limestone, NRCP, CRCP and CBOFS) are quite different from each other (see fig. 3). Ideally, the

Cement paste (dry) [w/w%]							
Mix	CEM I-52.5	Calcined clay	Gypsum	Limestone	NRFP	CRFP	CBOFS
Mix LS (Ref)	50%	32%	2%	16%			
Mix NRCP	50%	32%	2%		16%		
Mix CRCP	50%	32%	2%			16%	
Mix CBOFS	50%	32%	2%				16%

Table 1. Binder mix designs

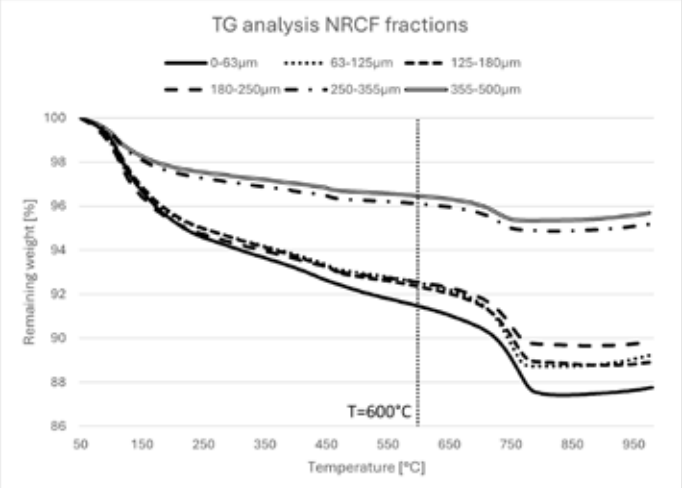

Figure 4. Thermogravitational analysis of NRCF fractions

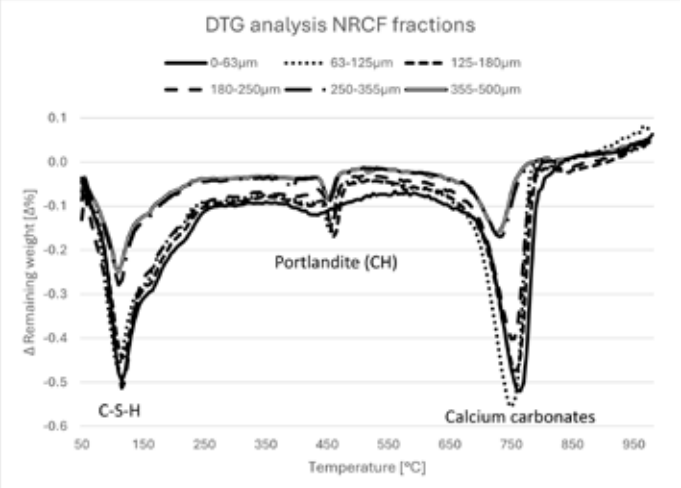

Figure 5. Derivative Thermogravitational analysis of NRCF fractions

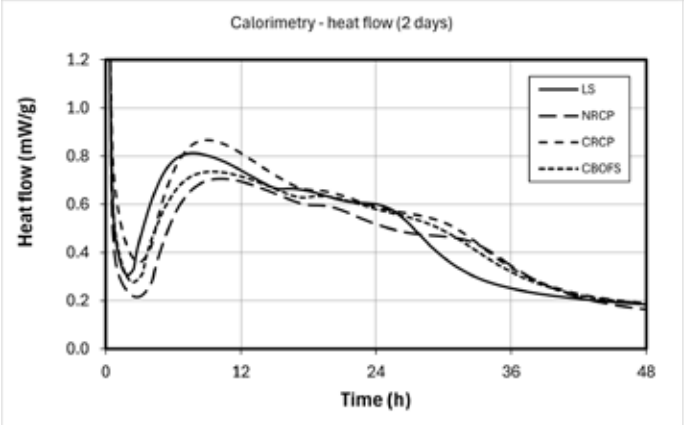

Figure 6. Calorimetry of binders with calcareous variants

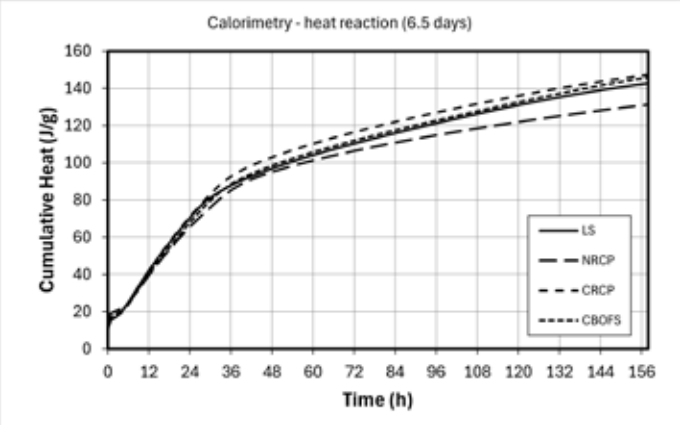

Figure 8. Cumulative calorimetry calcareous variants

Figure 7. Mortar prism samples

particle sizes should match each other approximately, so that the specific surface areas are comparable, but due to limited research equipment, it was not possible to further sieve the materials to match the limestone.

During a thermogravitational analysis test 40mg of materials gets heated to 950°C. During the heating the mass is recorded, and depending on the mass loss or gain at certain temperatures, it can be determined which components melt and vaporise. Thermogravitational analysis indicates that RCP (the smallest fraction, 0-63µm) has the most hydrated cement products (see figs 4 & 5). The figures show the most mass lost overall, especially at temperatures up to 600°C. This indicates a large presence of C-S-H and portlandite, two hydration products that are susceptible to carbonation. The DTG shows that RCP (0-63µm) is high in $CaCO_3$, which makes it interesting as calcareous material, even without carbonation.

Calorimetry shows how much thermal energy gets released over time upon hydration of the binder. The peaks are important as they indicate which reactions have taken place. Generally, each binder follows the same trend, with the highest peak early in the hydration process (see fig. 6). The first peak is the hydration of alite; the second peak is aluminate, as seen in other research [8].

The total thermal energy released over time is very close for limestone, CRCP and CBOFS, whereas NRCP has lower energy released (See fig. 8). This indicated that NRCP is less reactive than the other calcareous materials.

Mortar samples were made with a ratio of sand to binder to water ratio of 3:1:½. Prisms of 40×40×160mm were produced and hardened for 7 and 28 days (see fig. 3). They were tested for flexural strength in a 3-point bending testing setup, which broke the sample in two parts. These parts were subsequently used in compression strength testing. It can be observed that all strengths increase over time, which was expected (See figs 9 & 10). An interesting finding is the difference between flexural and compressive strength results: for flexural strength, the highest performance was achieved by using limestone, while for compressive strength NRCP yielded the highest strength. This could be explained by the higher reactivity of limestone regarding flexural strength, and more optimised particle packing from NRCP, but these claims warrant further research.

METHOD – ZERO-SLUMP CONCRETE

Zero-slump concrete mix designs were created with different size fractions of RCF. Three fractions were combined in different ratios: 0-250µm, 250-500µm and 500-2000µm (see fig. 11). Portland cement and water were added, and the mix was compressed in an Intensive Compaction tester, which produced cylindrical samples with a diameter and height of 100mm (see fig. 12). After unmoulding, one half of the samples was left to cure naturally for 24 hours; the other half of the specimens were inserted in a climate chamber for 6 hours, at 35°C, relative humidity 80%, and CO_2 concentration 20%. Afterward, they were removed and left to cure

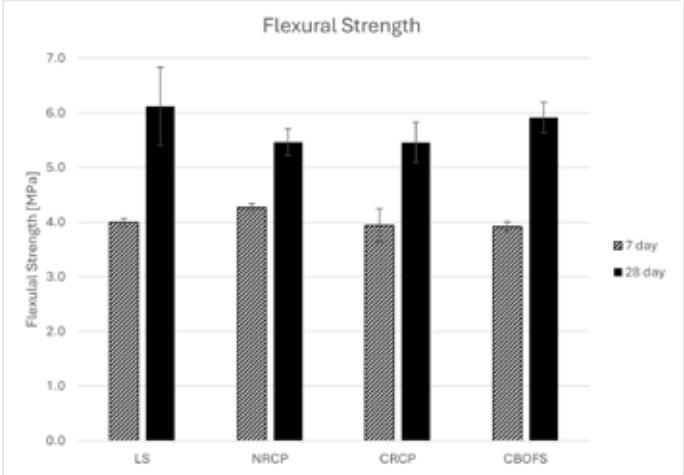

Figure 9. Flexural strength of mortar with different binder variants

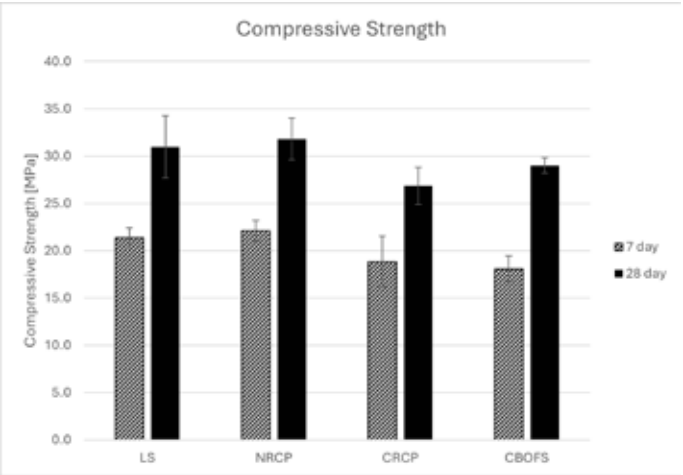

Figure 10. Compressive strength of mortar with different binder variants

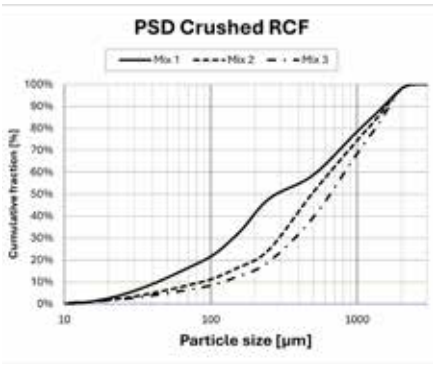

Figure 11. Particle size of RCF assemblies for zero-slump concrete

naturally for another 18 hours. After the curing period, the samples were tested for compressive strength, water absorption, chloride migration, and carbonation depth.

RESULTS AND DISCUSSION – ZERO-SLUMP CONCRETE

Carbon-curing increases the strength for all mixes; the largest difference occurred in the mix with the smallest RCF particles (see fig. 13). This makes sense, as the smallest particles contain the most cement remains and are therefor more susceptible to carbonation. The forming of calcium carbonate ($CaCO_3$) binds the particles and makes a stone-like material [9]. For the non-carbon-cured samples, the highest compressive strength is not linearly correlated with particle size. In fact, an intermediate mix of particle size causes the highest strength.

Carbonation depth measurement was performed with a phenolphthalein test, which indicated that carbon-cured samples has much higher carbonation depth than their non-carbon-cured counterparts. Carbonation depth also increased for smaller particle sizes, confirming the potential for unhydrated cement paste to carbonate.

CONCLUSION

In this study, the further recycling of recycled concrete fines was researched. RCP has potential to act as calcareous material in LC³ binders, showing similar strength results as limestone, and even outperforming the other calcareous materials in compression strength tests. Carbonation of RCF seems to offer little benefit to the strength, but still shows high reactivity as a SCM. This shows that chemically, CRCP has potential and that increase of specific surface area by decreasing particle size should yield even more reactivity, all the while sequestering CO_2 from the atmosphere. Additionally, carbon curing of zero-slump concrete shows much potential, as the 1-day strength is nearly doubled for mixes with a small particle size. This could lead to production of non-reinforced concrete elements such as building blocks. Further research should be done to optimise the reactivity by adjusting the particle size. ■

Figure 12. Unmoulding of ZSC specimen

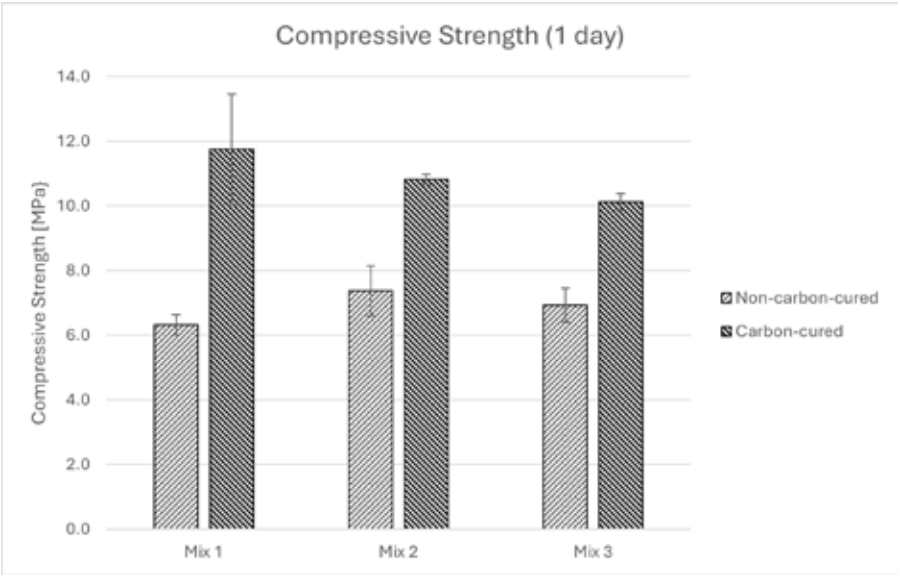

Figure 13. Compressive strength of ZSC

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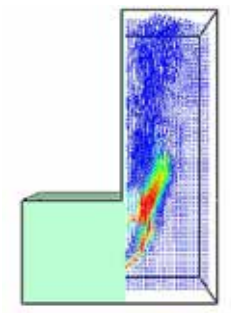



Experimental research on fire and response of structures, separation constructions and building materials

propagation, depending on fuel and building characteristics

Probabilistic approach of fire safety and fire protection objectives

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Engineering the Future of Heritage: The All-Electric Transformation of Venlo City Hall

Author
René Claessen
Kompas360

A RENAISSANCE LANDMARK IN A MODERN GRID

The Stadhuis van Venlo, situated prominently on the Markt, is an architectural jewel of the Dutch Renaissance. Originally constructed between 1597 and 1601 by Willem van Bommel, the building has survived centuries of urban evolution and the scars of World War II. Its iconic towers and stepped gables serve as a symbol of civic pride. However, for students of Building Physics and Services, the challenge lies beneath the aesthetic: how do we transform a 16th-century monumental structure into a high-performance, Label A, "All-Electric" facility without compromising its historical integrity?

As the primary advisors for building physics and technical installations, Kompas360 was tasked with bridging the gap between medieval masonry and 21st-century sustainability goals.

THE KOMPAS360 METHODOLOGY: FROM MJOP TO BESPOKE ADVICE

The project began with a tailor-made sustainability study (maatwerkadvies). Our approach was not to look at the building in isolation but to integrate the technical upgrades with the existing Multi-Year Maintenance Plan (MJOP). By aligning the sustainability roadmap with scheduled component replacements, we ensured a cost-effective transition that minimizes operational downtime.

THE GOLD LEATHER WALLPAPER: A MICRO-CLIMTE CHALLENGE

A unique constraint of this project is the preservation of the monumental gold leather wallpaper (goudleerbehang). This artifact is highly sensitive to fluctuations in hygrothermal conditions.

Figure 1. Stadhuis Venlo

• The Physics: Traditional heating methods often lead to sharp drops in relative humidity (RH), which can cause the leather to shrink and crack.

• The Solution: Kompas360 designed specialized adjustments for the Air Handling Units (AHUs) to ensure indoor air conditions remain strictly within a narrow bandwidth of temperature and moisture content. This requires sophisticated sensor arrays and modulated control logic to prevent "sawtooth" fluctuations in the indoor climate.

OVERCOMING GRID CONGESTION: THE ALL-ELECTRIC vs. HYBRID DEBATE

In the current Dutch energy landscape, grid congestion is a significant barrier. Initially, a hybrid installation (Heat Pump + Gas Boiler) was considered to shave peak loads. Kompas360 conducted an exhaustive comparative study between Hybrid and All-Electric configurations using Total Cost of Ownership (TCO) calculations.

While hybrid systems offer lower peak electrical demand, they fail to meet the Municipality of Venlo's ambitious decarbonization targets. By performing a rigorous energy balance (covering heating, cooling, ventilation, lighting, and auxiliary power) and an electrical capacity calculation, we proved that the building could function entirely without gas. By optimizing the three existing Enexis electrical connections, we successfully navigated the constraints of the local grid, making the building truly "Future Proof".

TECHNICAL INTERVENTIONS: BUILDING PHYSICS & SYSTEMS

To achieve the Label A status, Kompas360 specified a dual-track strategy of architectural and mechanical interventions.

1. Improvements of Building physics

Due to the monumental status of both the interior and exterior, traditional wall insulation was prohibited. Our strategy focused on the "envelope of least resistance":

• Attic Insulation: The attic floor—which serves as the primary technical plant room—is being heavily insulated to thermalize the building's crown.

• Secondary Glazing: All stained-glass windows will be fitted with HR++ secondary glazing (achterzetramen). This improves the U-value significantly while preserving the original glass and protecting it from acoustic pollution and condensation.

2. Mechanical & Electrical Engineering (Installatietechniek)

The transition to All-Electric necessitates a complete overhaul of the energy plant:

• Heat Pump Plant: The existing gas boilers and chillers are being replaced by two high-capacity heat pumps. These units are sized not just for current loads, but for the municipality's new vision of use, which anticipates higher occupancy and increased ventilation requirements.

• Air Handling: We are replacing two AHUs with units capable of higher flow rates (m^3/h) to meet modern CO2 standards and the specific needs of the Mayor's office (the gold leather room).

• Electrical Infrastructure: To manage the increased load within the limits of grid congestion, Kompas360 is redesigning the distribution boards and feeders. This ensures that the high-power demand of the heat pumps does not trigger local circuit failures.

• Control Systems: A full replacement of the Building Management System (BMS/ Regeltechniek) is underway to allow for the precision control required for the energy-neutral ambitions.

CONCLUSION: ENGINEERING LONGEVITY

The project is currently concluding the engineering phase. With financial frameworks finalized and contractor signatures imminent, the transformation is moving into execution.

Kompas360 will continue to provide intensive supervision until completion. By the end of this cycle, the Venlo City Hall will stand as a beacon of sustainable heritage—a "Future Proof" monument that requires only routine maintenance for the next 20 years. For the students at TU/e, this project serves as a case study in how technical constraints, when met with innovative engineering and rigorous TCO analysis, can preserve the past through the technology of the future. ■

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The Fire Resilience of CLT Compartments

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Supervisor
ir. R.A.P. (Ruud) van Herpen

INTRODUCTION

Since sustainability has become a more important subject throughout the years, the material use and construction processes in the built environment have adapted to reduce its impact on the environment. An example of this is the use of timber in building structures, specifically the use of Cross Laminated Timber, also known as CLT. CLT is a flammable structural material, and can play a significant role in the case of a fire [1]. While there are several fire safety guidelines, fire resilience is a concept which is important in the view of sustainability, since a fire resilient structure ensures the durability of a building and its materials, as it is restorable post-fire and does not require demolishment [2].

In this study, the role of a CLT structure in the case of a compartment fire and its effect on fire resilience is researched in the context of the natural fire concept. Furthermore, the influence of different levels of fire-resistant protection in a CLT compartment is determined. This knowledge can aid in a deeper understanding of the effects of the use of flammable materials in building structures and what this means for sustainability.

METHODOLOGY

For the comparison of the effects of different levels of fire-resistant protection in a CLT compartment, six scenarios were devised, alongside a scenario completely without fire-resistant protection. The walls and ceiling have a respective CLT thickness of 0.11 m and 0.16 m. The protected surfaces also have two 0.0125 m layers of gypsum fire-resistant protection, and the top of the floor has a 0.10 m concrete topping, since it is assumed not to participate in the fire. For each of the scenarios, both the permanent fire load, and the Rate of Heat Release of the exposed CLT construction elements, for several temperature intervals, were determined based on the exposed surfaces, their respective thicknesses, and data from previously performed experiments from the mass loss of CLT for different radiation heat fluxes [3].

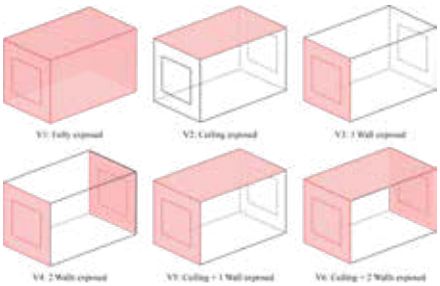

Figure 1. Simulation scenarios

The simulations were performed with the use of the software OZone 3 to determine the evolution of compartment fires. In the simulations, the external flaming concept was used, indicating not all energy is maintained within the compartment and can escape through the large openings. [4] The natural fire concept used in this software aids in the understanding of a fire resulting from the influences of its natural dynamics [5]. The simulations were performed iteratively for each temperature interval, with its corresponding RHR. The iterative simulations resulted in either a burn-down scenario or the fire dying out on itself, meaning that part of the structure remains. With the data from the simulations, the burned permanent fire load and the equivalent fire duration were computed to evaluate the fire resilience of the scenarios.

CONCLUSIONS

The simulations showcased that, for one exposed surface, the CLT structure could be deemed fire resilient, as there is no burn-down scenario and the fire-resistant protection does not fail. This is illustrated in Figure 2 in the gradual reduction of the temperature in the compartment for V2-V4. Aside from the scenario with only two walls exposed, scenarios with multiple exposed surfaces are not deemed fire-resilient, since each scenario experiences a burn-down scenario, illustrated in Figure 2 by the abrupt reduction in compartment temperature for V1, V5 and V6. Due to the simplicity of the software, multiple parameters could not be implemented in the simulations, such as the effects of charring and heat delamination of CLT, failure of the fire-resistant protection and the effects of multiple radiating surfaces. Further research is required in order to determine the effects of these parameters on the fire resilience. ■

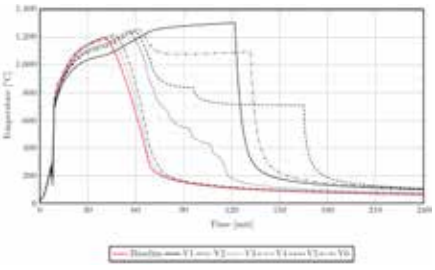

Figure 2. Temperature Evolution over Time for Compartments V1–V6

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Fire Loads in Escape Routes: Ensuring Equivalent Fire Safety in Senior Housing

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Supervisors
Ruud van Herpen (TU/e)
Mirjam Roth (VRZHZ)

INTRODUCTION

In the Netherlands, fire safety in the built environment is governed by the Besluit Bouwwerken Leefomgeving (Bbl). A fundamental principle regarding escape routes is the strict limitation of fire loads to ensure these paths remain usable during an evacuation. For residential buildings with a care component, such as senior housing, prescriptive regulations often prohibit combustible materials entirely in shared escape routes. This is intended to prevent smoke and heat radiation from blocking the only exit path for residents with reduced self-reliance.

However, this no-tolerance approach frequently conflicts with the social and functional requirements of modern elderly housing. Large atriums and corridors are designed as central social hubs where furniture, such as billiard tables, plays a vital role in residents' mental well-being. This creates a tension between social necessity and prescriptive fire codes [1].

THE RESEARCH GAP

Currently, fire safety specialists and Dutch Safety Regions (Veiligheidsregio's) lack a standardized, scientifically supported methodology to allow such items under the principle of Equivalent Safety (Gelijkwaardigheid). While existing manuals provide frameworks, they often rely on generic furniture fire curves [2]. These do not account for the complex material composition of a billiard table, hardwood frames, vulcanized rubber, and wool-synthetic blends, nor the specific evacuation needs of vulnerable populations. The goal of my research is to replace these generic assumptions with object-specific fire engineering.

A GLOBAL BENCHMARK FOR VULNERABILITY

To define safety for the elderly, this research looks beyond Dutch

Figure 1. Full-scale fire testing of a billiard table at the Peutz laboratory.

Figure 2. Full-scale fire testing of a billiard table at the Peutz laboratory.

borders to the Swedish Building Code (BBRAD). In the Dutch context, there is a lack of specific quantitative tenability limits for seniors. By adopting Swedish standards, we apply a 2/3 reduction factor to standard walking speeds and set higher visibility thresholds (10 meters) to account for reduced sensory perception [3].

EXPERIMENTAL VALIDATION

The heart of the project is a series of full-scale experiments conducted with Peutz b.v. in Haps. We focused on traditional hardwood tables to determine the actual Heat Release Rate (HRR) and Time to First Smoke. Determining this detection window is essential when designing for a population that moves significantly slower than the average adult [4].

ROADMAP TO COMPLETION

With the laboratory phase concluding, the project is now moving into its final phases of numerical simulation and synthesis:

1. Numerical Fire Modeling (CFAST): The experimental HRR curves will be imported into CFAST to model a baseline 12-meter high atrium. This phase includes a sensitivity analysis to see how the smoke layer behaves across different building geometries and ventilation capacities.

2. Evacuation Simulation (Pathfinder): Using Pathfinder, the Required Safe Egress Time (RSET) will be simulated for 20+ residents. This model explicitly accounts for impaired mobility and the limited number of staff available to assist during an emergency.

3. ASET/RSET Comparison: The final analysis will compare the Available time (before smoke drops to 2.8 meters or heat radiation exceeds 1 kW/m²) against the Required time [5].

4. Final Recommendation: The project will conclude with a practical framework for the Safety Region Zuid-Holland Zuid (VRZHZ). This will provide fire officers with a technical ground to approve or mitigate the presence of social furniture in atriums based on scientific evidence rather than generic bans.

Through this performance-based approach, we can protect lives without sacrificing the quality of life and community that makes a facility feel like a home. ■

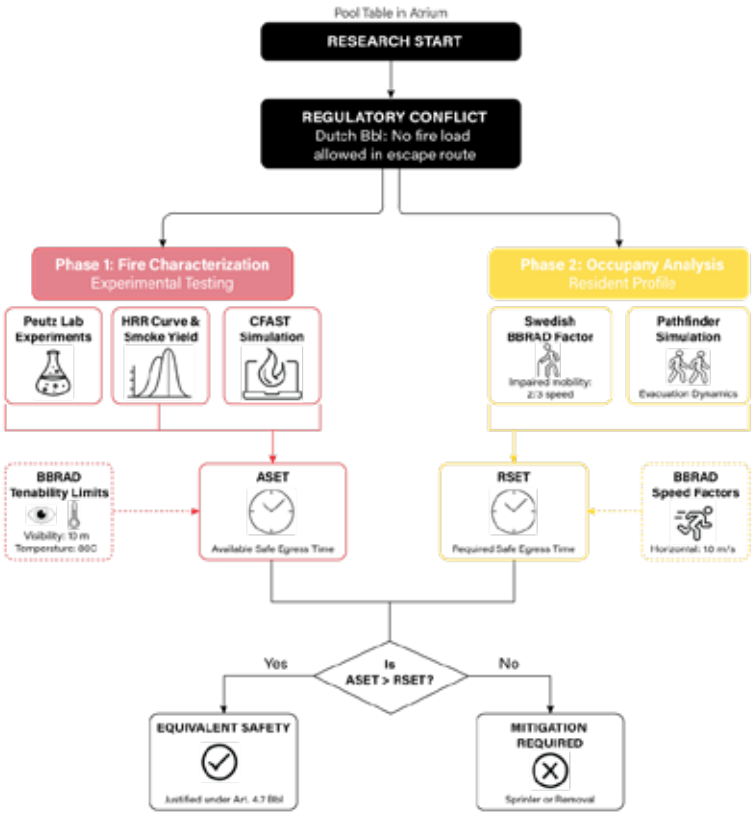

Figure 3. Methodology of the research project.

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dGmR

Ice Breaker
Alex van Diepen

Hello, my name is Alex van Diepen, and I am a first-year master's student in the Building Physics and Services (BPS) track of the Architecture, Building and Planning (ABP) master. I currently live in Eindhoven, but I grew up in Wijchen, a town in the east of the Netherlands near Nijmegen. I completed my Gymnasium diploma in Nijmegen.

When I was choosing a university program, I only knew one thing for sure: it had to be something technical. When I went to the open days at the Technical Universities in the Netherlands, I expected to narrow my interest down, but instead I found almost every study interesting. Ironically, the only study that I could rule out was architecture at the TU Delft. However, when I arrived in Eindhoven, I was surprised by what they had to offer with the bachelor Architecture, Urbanism and Building Sciences (AUBS). The strong technical focus of the program, which I missed in Delft, immediately appealed to me, ultimately convincing me to enrol.

During my bachelor's, my interest in the more technical side of the study became even bigger, as I preferred the courses in the SED and BPS track. This made me face a difficult new decision: follow the SED or the BPS track? After some consideration, mainly the courses Building Physics & Building Services, and the bachelor end project, from which the infrared thermography image of Figure 1 is retrieved, helped me in this decision. The wide variety of subjects in BPS, and the different ways of thinking they require really spoke to me and made me choose BPS over SED. And I'm still very happy with this decision.

Because I missed actually applying my knowledge in the real world, and disliked hearing the term "that is out of the scope of this project", I joined VIRTU/e in my second year of my

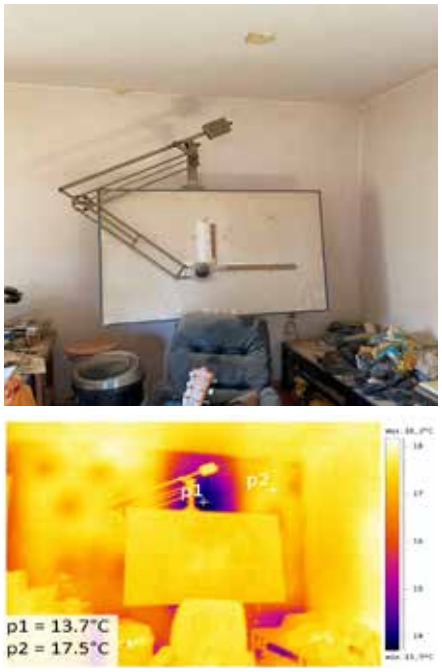

Figure 1. Thermal bridge on the inside identified during my BEP project through infrared thermography

bachelor. VIRTU/e is a multidisciplinary student team designing and realizing sustainable building concepts. During this time, I could apply the learned knowledge from the courses in a real-world context. This not only helped me understand certain subjects better, but also improved my understanding of why certain knowledge is essential. And not to forget, it was also a really fun experience to work together with amazing people!

Alongside my master's, I started working as a working student at the building physics consultancy firm Nelissen Ingenieursbureau. Here, I work on a wide variety of projects with all sorts of tasks. These can range from daylight calculations to fire safety analyses. This role has helped me better understand the requirements and course of a building project while significantly strengthening both my technical and professional skills, especially within the Dutch context. The open and helpful environment at Nelissen encourages me to ask questions, while also challenging me to think critically and develop my own understanding.

At the moment I am still exploring what I want to do after my studies, but there is a high chance that it will be something similar to my current job.

Besides my studies, I also have some other hobbies, which I think are essential to relax and clear my head. Since I turned six, I have been playing field hockey at my local club in Wijchen. I still enjoy the feeling of stepping onto the field and being fully focused on only the game. Additionally, I also enjoy running and hiking, especially in the mountains. The complete silence, astonishing views, and challenging paths are just unbeatable in my opinion. During holidays, I prefer exploring both nature and cities, as I am not someone who enjoys sitting still for too long.

Figure 2. Mountains somewhere in the North of Norway

Overall, I am excited about the path that I have chosen and look forward to further developing myself within the field of building physics and services. I am looking forward to meeting all of you. ■

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Comparing Open-Source Room Acoustics Simulation Tools: Performance and Usability Insights

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INTRODUCTION

In building practice and academic research applications, simulation tools are commonly used to predict room acoustics. Applications for these tools in building practice include assessing the quality of room acoustics in the design stage of a building, where measurements are not yet possible since the building has not yet been constructed. Another application of such tools can be assessing the impact of changes to an existing room on the acoustics in the space. Examples of rooms where these tools can be used are auditoriums, classrooms, cinema's, concert halls, large parking spaces and many more.

Many commercial tools are available that achieve this goal. In recent years, open-source room acoustic simulation tools have increasingly been shared, free to be used and redistributed by anyone subject to the license conditions. These software open the potential to accelerate science and offer opportunities for reproducibility of the results [1].

In previous decades, many studies have been conducted on the development and evaluation of simulation tools for the prediction of room acoustics using computer simulations. Figure 1 shows the previously researched software found in a systematic literature review, along with their software license type. It is clear that commercial software has been studied most extensively. A total of 11 publications evaluated the simulation performance of ODEON [2], which makes it the most extensively evaluated tool. Other commercial tools were found to be evaluated less extensively. None of the publications found reported any information on the subjective user aspect of the simulation tools. Furthermore, none of the publications report their reasons for choosing a particular simulation tool for the comparisons.

In their research, Hornikx et al. (2024) performed a literature study in five databases, including GitHub and Paperswithcode, to find open-source simulation tools specifically designed for the simulation of room acoustics. As a result, they found 55 unique open-source simulation tools [3]. The results in Figure 1 hint to a lack of understanding the simulation quality of these open-source room acoustics simulation software, since in this literature study only two tools were found. In addition, existing literature shows the need for a reproducible method for the comparison of the performance of both open-source and commercial tools.

Only three studies reported some simulation settings. Additionally, no previous publications report the usability of the software. For the adoption of room acoustic simulation tools and thereby the enhancement of its value, in particular for open-source software, information on the usability of the software is important. With a good usability of simulation tools, users might be more inclined to return to the simulation tool for future tasks.

This research aims to develop a reproducible method for the evaluation of simulation software for room acoustics based on various computational methods. Reference rooms from databases available to anyone were used. The aim is to compare the simulation quality of these various tools using common parameters for room acoustics to measurements conducted in the room. Further evaluation of various tools, available now and in the future, using the method developed in this research is encouraged. Additionally this research

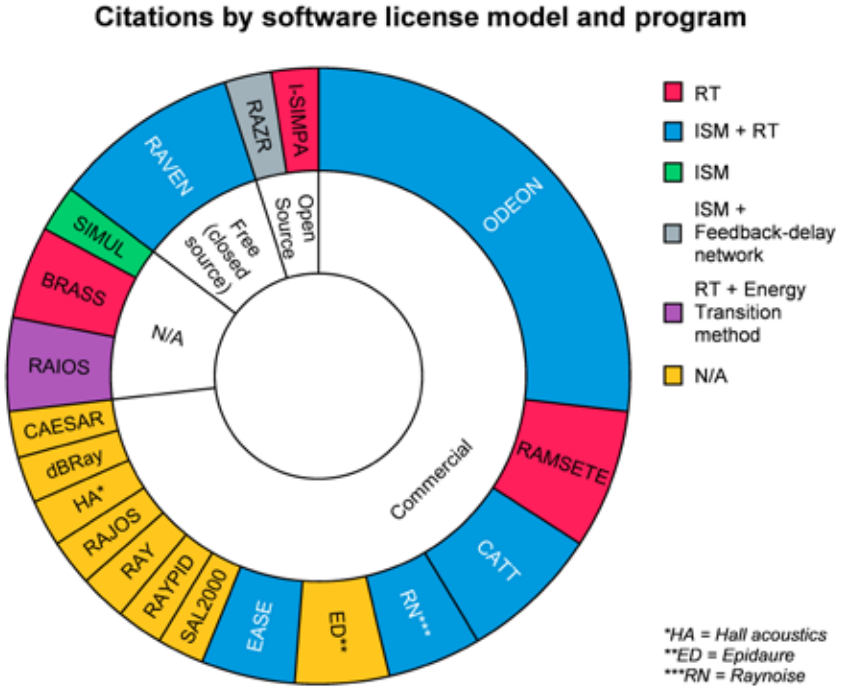
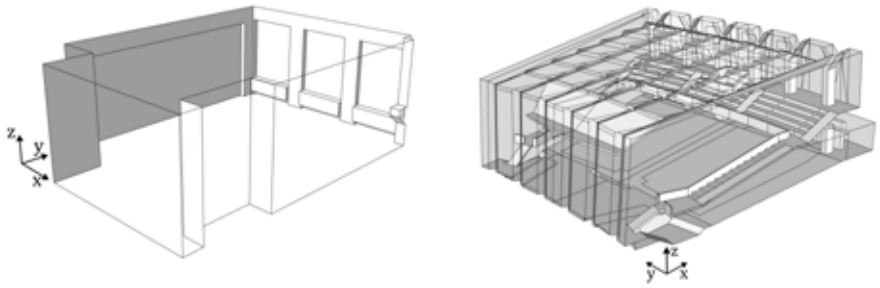


Figure 1. Overview of room acoustics simulation software found in existing literature. Presented are software names, license types, computation methods, and the amount of found publications.



(a) (b)

Figure 2. The two rooms used in this benchmark, CR2 (a) and CR4 (b).

aims to be a starting point for a more in-depth research into the usability of software for the simulation of room acoustics. The goal of this research is to show the potential for software development of such research, since valuable insight is gained of the usability of these tools. A result of research in this field could be the improvement of usability of tools for room acoustics for applications both in academic and building practice.

METHODOLOGY

Simulation software performance

Rooms were selected from the Benchmark for Room Acoustics Simulation Software (BRAS) database. This database contains four rooms in which Impulse Responses (IRs) were measured on documented source and receiver positions. Furthermore, material absorption and scattering data in 1/3-octave bands from 20 to 20000 Hz are provided. Additionally, the room geometry is provided as a 3D-SketchUp model [4].

In this research, two rooms were chosen as the reference rooms. Complex Room 2 (CR2) was chosen for its relatively small size, offering the possibility to gain insights into the prediction of wave interaction on lower frequencies. The second room, Complex Room 4 (CR4), is a large auditorium. This room is very different from the small room, offering insights into the prediction of room acoustics by the different simulation tools of two very different rooms. The rooms are presented in Figures 2a and 2b.

For the evaluation of the simulation performance of the selected tools, common objective parameters for room acoustics and their respective Just Noticeable Difference (JND) range from ISO 3382-1 will be used [5]. The simulated results will be compared to the measured data in the rooms. Post-processing of the simulation and measurement results using the computed impulse responses as .wav files was preferred over extracting simulation results computed by the software. To ensure consistent post-processing, a custom MATLAB script was developed using the ITA-toolbox [6].

The open-source room acoustics simulation tools to be evaluated in this research were chosen based on the pre-determined conditions, which are requirements for the researcher to use the different tools:

- The software runs on the Windows operating system.
- The software is specifically designed for room acoustics simulation.
- Documentation of the software is available. This can be an installation guide or a user manual.
- The software contains a description of the computation method, this could for example be a scientific publication.
- Detailed 3D geometry input is possible.

For comparison purposes, commercial simulation tool Treble was added to the software list.

The selection stage resulted in the selection of the simulation tools provided in Table 1.

For a fair comparison between the software, the simulation settings should be consistent. Due to their fundamental differences, separate settings for Geometrical Acoustics (GA) and Wave-Based (WB) methods were determined and reported in the thesis. The simulations should provide sufficient detail to compute energy-based room-acoustic parameters. Simulations for auralization purposes are out of the scope of this research. Machine-learning (ML) models each employ their own computation methods, and thus general settings cannot be determined.

Existing literature shows the need for a reproducible method for the evaluation of simulation tools for room acoustics. For this reason, the research in this thesis has been conducted with a strong focus on reproducibility.

Supplementary materials of this thesis are available for reproducibility and further research purposes[1]. The reference rooms evaluated in this thesis are part of the BRAS database. The simplified room models are available as SketchUp, and .obj files in the supplementary materials. x, y, and z positions of the sources and receivers, in accordance to the supplied simplified 3D-room geometries, are also provided in the supplementary materials. For completeness, the supplementary materials also include absorption and scattering coefficients of the materials in 1/3-octave bands as .csv files [4]. To ensure reproducibility of the results in this thesis, all simulated IRs are available as .wav files in the supplementary materials. The script to compute the objective room acoustic parameters from the simulated IRs using ITA-toolbox is also provided. Furthermore, all necessary program files are available in the supplementary materials.

Software usablility

In this research, the usability of the simulation tools used (Table 1) was assessed. The goal of the usability study is to offer first insights into the usability for the open-source simulation tools. As a result, the performed usability study might offer the potential for a more rapid adoption of open-source room acoustics simulation tools in building practice and academic research.

A full usability study is out of the scope of this thesis. The usability of the used tools is evaluated from the viewpoint of one user. This approach fits the goal of this study, since the goal is to offer first insights into the usability of the simulation tools. For a usability study, the user characteristics, task and aim of the study need to be clearly described and are available in the thesis.

Table 1. Overview of the simulation software subject of the current research.

Software name	Method	License type	Version (v) / Date of use (DoU)	Reference
Pyroomacoustics	GA	Open-source	0.8.2 (v)	[7]
I-Simpa	GA	Open-source	1.3.4 (v) SPPS*: 2.2.1 (v)	[8]
ParallelFDTD	WB	Open-source	7-Jun 2022 (v)	[9]
dg-acoustics	WB	Open-source	28-Oct 2024 (v)	[10]
Image2Reverb	ML	Open-source	12-Oct 2021 (v)	[11]
Mesh2IR	ML	Open-source	29-dec 2023 (v)	[12]
Treble	GA + WB + ray-radiosity	Open-source	CR2: 10-Dec 2024 (DoU) CR4: 15-Apr 2025 (DoU)	[13]

*SPPS is the computational model built in I-Simpa, based on RT

Footnote 1: https://github.com/Building-acoustics-TU-Eindhoven/OSS RoomAcoustics

In the thesis, the usability of the tools used was assessed using Nielsen's "Ten Usability Heuristics for User Interface Design" [14].

RESULTS AND DISCUSSION

Results

While the goal was to use the simulation tools presented in Table 1, two simulation tools were not used due to various complications. In this article, only the results for room CR2 are presented. Additional results are available in the thesis [17]. The simulated results are compared to the measured room acoustics parameters as discussed according to ISO 3382-1 [5]. The measurement and simulation results are presented in Figure 3.

Based on the two rooms used in this research, the overall simulation performance of the used simulation tools was found to be generally comparable between the various tools. Of the GA-solvers, I-SIMPA and Treble seem to estimate the room acoustics closest to the measured results. Pyroomacoustics shows large deviations from the measured results, with the exception of the reverberation time metrics both rooms. Both wave-based solvers, dg-acoustics and Treble, show similar performance in both rooms.

The machine-learning tool Image2Reverb shows comparable results to the tools based on conventional GA and WB-methods in both rooms, especially above the Schroeder frequency in the rooms.

For each tool, usability issues and potential improvements were found and described in detail according to Nielsen's Usability heuristics. These results are available in the Thesis [17].

Discussion

In this research, the objective quality of the simulations was evaluated using objective room acoustical parameters. However, a large part of a simulation is also the subjective quality of the simulation result, which can be assessed through an auralization study. These studies require a sufficiently large group of test subjects, and is out of the scope of this research.

In this research, simulation results of two rooms are presented: a small seminar room (CR2) and a large auditorium (CR4). These rooms provide a good general idea of the prediction quality of the various open-source simulation tools using various simulation methods. Furthermore, these two rooms have proven to be effective of finding possible shortcomings of the simulation tools. The introduction of additional rooms might offer more insights into the prediction quality of the room acoustics of these used open-source simulation tools. This, as a result, may offer researchers and building designers more insights into the correct tool to use for a specific room.

In this research, four open-source simulation tools for room acoustics were evaluated on their prediction quality. These were chosen based on pre-determined conditions. Many more promising open-source tools for room acoustics are available. The tools used in this thesis offer valuable insights into the potential of open-source simulation tools for room acoustics: the tools can offer comparable results to often used commercial simulation tools and they may require some time to get used to.

For the wave-based solvers, real and imaginary reflection coefficients were required. However, only random-incidence absorption coefficients were available in the database. It was decided to use a closed-source implementation of the method proposed by Mondet et al. (2020) [15]. While this is not fully reproducible, all computed real and imaginary reflection coefficients are reported in the supplementary materials.

The suggested usability improvements of the simulation tools are not representative for the broad perceived usability of the software. Rather, it represents the experience of a single user with the software tools., which is by far not representative of the general usability of the software. However, the goal of this research is to encourage more research into the topic of software usability for room acoustics simulation software. Therefore, while not fully representative, the current work offers a first insight into the possibilities and encourages future work on this topic.

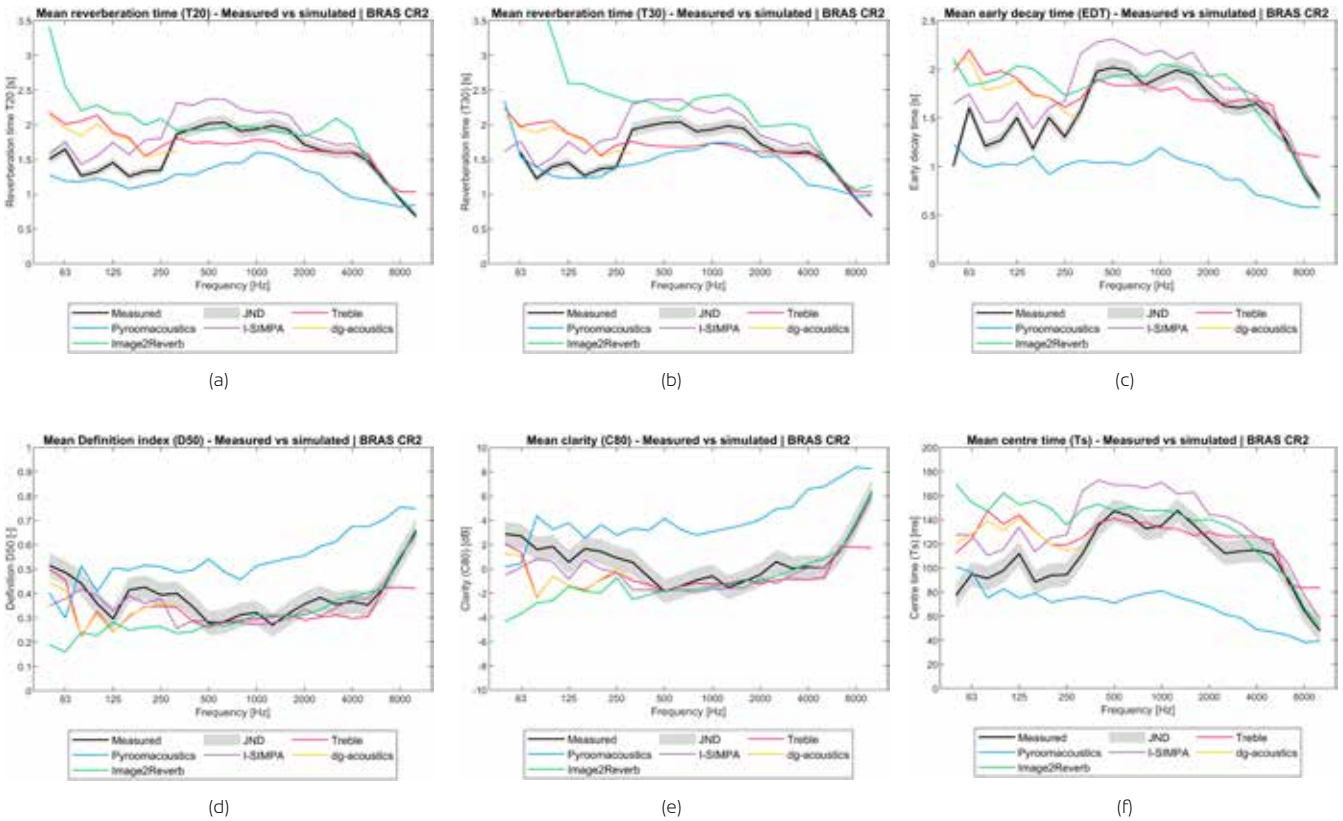


Figure 3. Mean measured and simulated results in reference room CR2. Presented are reverberation times T20 (a), T30 (b), EDT (c), center time Ts (d), definition D50 (e) and clarity C80 (f).

CONCLUSIONS

In building practice and academic research applications, simulation tools are commonly used to predict room acoustics. Many commercial tools are available for this purpose. In recent years, open-source room acoustics simulation tools have increasingly been shared, free to be used and redistributed by anyone subject to the license conditions. The simulation performance of commercial tools is relatively often evaluated previously. However, existing literature shows a lack of a reproducible method for the evaluation of simulation tools for room acoustics.

In this thesis, a methodology was developed for the systematic evaluation of simulation tools for room acoustics. The method utilized two benchmark rooms from the BRAS database, however can be easily expanded to other rooms [4]. The aim of the methodology was to develop a reproducible and expandable method. In previous research many simulation parameters, of which the room models and simulation settings are examples, were not reported. The selection of tools included a methods based on GA, WB and Machine-Learning methods. The goal was to assess the prediction quality of these tools using objective room acoustics parameters from ISO 3382-1 [5]. The open-source tools were compared to simulation results from Treble, a commercial tool. In addition, the usability of the open-source simulation tools was assessed. Supplementary materials of this thesis are available[1], which ensure reproducibility and expandability of the method developed in this thesis.

The results show that open-source room acoustics simulation tools can be valuable tools for the simulation of room acoustics. Results show comparable deviations from the measured results by all used simulation tools. Simulations were performed in a small lecture room, and a large auditorium.

The results show varying agreement with the measurement data. Reverberation times are mostly predicted outside of the JND-range by both the open-source and commercial tools. In the large room, most tools tend to overestimate the reverberation time, with the exception of Pyroomacoustics which underestimated the reverberation time. The WB solvers tend to overestimate the reverberation time in the octave bands below the Schroeder frequency. Definition and clarity parameters are predicted mostly within the JND-range by both the open-source and commercial tools. Only in the small room, below the Schroeder frequency, the predictions show deviations from the measurements. Pyroomacoustics is the only exception, which tends to overestimate the clarity and definition in the rooms.

In this research, the usability of the used simulation tools was assessed from the viewpoint of a user of simulation software for room acoustics. The user has three years of experience with performing acoustics simulations and with performing room acoustic measurements. However, the user has limited experience in coding and bugfixing.

All open-source simulation tools, with the exception of I-SIMPA, lack a user-friendly Graphical User Interface (GUI). The documentation, installation instructions and examples were found to be generally inconsistent or incomplete. Finally, most tools do not offer feedback to the user concerning the simulation status when it the simulation is running. Specific usability problems for each simulation tool were discussed in the thesis.

The usability assessment in this thesis is not comprehensive. For a comprehensive usability assessment, the tools should be assessed by a sufficiently large user group using usability scales and other methods for the evaluation of usability [16]. However, it was shown that no previous studies evaluating the simulation performance of room acoustics discussed the usability of the tools used. The results in this thesis, therefore, offer valuable first insights into this aspect of performing room acoustics simulations. Furthermore, it shows the potential for a more comprehensive study into software usability in the context of room acoustics simulations. ■

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Unveiling Antwerp:
A Recap of the MDE 2025-2026

Author
Andreas Hehn

From April 17th to 19th, we held our annual multi-day excursion to Antwerp. The trip was organized to provide a balanced look at different stages of the building process: starting with innovative material research, moving to the restoration of historic monuments, and concluding with modern sustainable office design. By visiting both active laboratories and completed architectural landmarks, we were able to see how theoretical research translates into the built environment. Beyond the academic program, the trip also served as a fun way to explore the city of Antwerp through all kinds of activities.

We kicked things off at MNext's laboratory in Breda, where we gained valuable insights into their research on bio-based materials - specifically mycelium - and its applications from insulation materials to load-bearing structures in the built environment and other fields, such as leather substitutes in clothing. We were also shown how mycelium is grown and transformed into a usable product by touring us in their lab. In a small workshop, students were also shown how to do the first step of this process themselves.

Figure 1. Presentation on mycelium as a building material at MNext's laboratory

From there, we headed to Antwerp, where we had the opportunity to visit the City Hall on a guided tour by René van Poppel, the project architect of the building's renovation. We learned about the restoration process and the challenges of retrofitting historical buildings while meeting today's building standards. But most importantly, we took in the beautiful interior of the hall.

Figure 2. Arrival in Antwerp

Later on, we finished the first day with a fun pub quiz which included questions of general knowledge, facts about Antwerp, and, of course, BPS. The night wasn't over yet, as the group then went out to try the city's nightlife.

Day two brought us to the Provincie Huis of Antwerp, an outstanding example of contemporary architecture and Antwerp's first passive governmental building. We delved into the active and passive strategies behind its design and the thinking that shaped it. As we visited on the weekend, we had the chance to get a peek behind the scenes of its operation, wander through the offices and chamber of the provincial council of Antwerp, and see the spaces that the employees use daily.

Figure 3. Group picture in the Provincie Huis of Antwerp

We then split and discovered the city by playing our "escape the city" game, where participants found themselves in a goofy adventure involving Richard Mollier, leading them through the major attractions of Antwerp. Upon answering the posed questions correctly, background information and fun facts were revealed for each location.

We then ended the day with a pub crawl, where we stopped at several bars carefully hand-picked by our committee in the city.

On our last day, we toured the MAS museum, where we viewed both the temporary exhibition about martial arts and its history, and the permanent exhibitions. Besides the architecturally interesting curved glass facade of the building, MAS also offers a gorgeous panoramic view from the rooftop, which is also free to access.

Finally, we wrapped up the trip with a well-deserved dinner at Fogos Antwerpen, a Brazilian all-you-can-eat restaurant offering an endless spread of meat, seafood, and side dishes and salads that kept getting better with every round. What a weekend! ■

Figure 4. Group dinner at Fogos Antwerpen


MNEXT

Explosion Safety of Facades: Regulations and Practice Concerning Shatterproof Glass

Author
Ir. E.R. (Esther) Heblij
DGMR

Explosion safety of facades is increasingly becoming a focus of attention in projects. This is due to a relatively new requirement in building regulations. It protects against the risk of injury from incidents along transport routes and at high-risk industrial sites. Windows must be fitted with "shatterproof glass" for this purpose, but there is no legal method for determining this yet.

The production and transport of hazardous substances is not without risk. Although much is being done to minimize risks, there remains a chance of incidents involving the explosion of a storage tank or tanker. A realistic scenario is, for example, a hot Boiling Liquid Expanding Vapour Explosion - an explosion of a gas tank caused by a fire. The fire causes the pressure in the tank to rise, which can cause the tank to rupture. The released gas causes an enormous pressure wave and a fireball. The pressure on the windows 50 metres from the road can be more than 25 times the wind load for which the window is designed. Many standard windows will shatter and the shards will fly into the rooms at high speed, where they can cause casualties.

In July 2025, such a hot BLEVE explosion occurred in Rome. While transferring LPG from a tanker truck, an explosion occurred, injuring more than forty people. The force of the explosion blew the roof off the petrol station and it landed 300 metres away. In addition, dozens of windows in surrounding buildings were shattered.

EXPLOSION REGULATIONS

The Environment Act includes regulations with improved protection against explosion. For designers and builders, it is important to know whether an area has been designated as an explosion regulation area in the Environmental Plan. It also happens that a municipality has not yet designated the explosion regulation areas in the Environmental Plan. In a spatial planning procedure, the area is then designated ad hoc as an explosion regulation area.

DIFFERENT INTERPRETATIONS

How to determine whether the chosen glazing prevents injury from glazing shards? There is no assigned method of determination, this leads to uncertainty among project developers, contractors and clients. We have already counted fifteen different interpretations of how to implement the requirement. In some cases, this is due to unfamiliarity with the subject. Sometimes there is a conscious consideration behind it, in which an optimum balance was sought between the feasibility of the project and the reduction of many casualties, given the very small chance of such an accident occurring at that location. Coordination with authority on the method of assessment is recommended for a smooth process.

WHEN IS GLASS BLAST PROOF?

There is no legally prescribed method to determine whether glass is suitable in the event of an explosion. However, the objective is clear: preventing injury caused by shattering. This means that glass fragments must not fly in at high speed. The glass may, however, break, if the glass splinters fall directly behind the window.

This interpretation is most consistent with the GSA-TS01-2003 assessment method developed by the U.S. GSA (General Service Administration) and the ICS (Interagency Security Committee) of the U.S. Department of Homeland Security. To minimize the risk of injury, a class 1, 2 or 3a is sufficient.

We can use software that has been validated based on explosion tests and finite element calculations. This method from Wingard PE uses the dimensions and deformation capacity of the glass in the building, the complete structure of the interior and exterior glazing, and the method of clamping in the frame rebate.

And, very importantly, the fact that glass can withstand significantly more stress during a very short pressure wave lasting a few milliseconds than when calculated statically according to the method for flat glass described in NEN 2608.

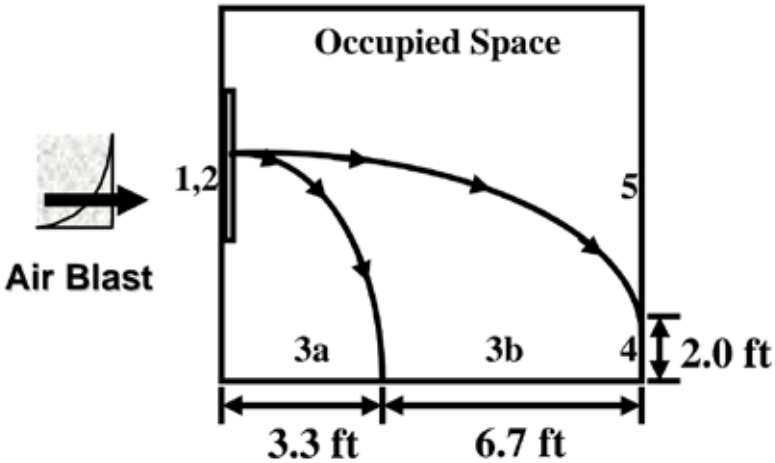

Figure 1. The location where glass fragments land after an explosion determines the risk of injury. (Source: GSA-TS01-2003)

The method also offers major advantages over certified explosion-resistant glazing according to the private law standard NEN-EN 13541 (Testing and classification of resistance to explosion pressure), in which one square meter of glazing in a steel frame is tested. This test method is far removed from practical application, which means that under- or oversizing is a possibility.

INFLUENCE OF FRAME OR FACADE

The regulation does not mention the frame in which the glazing is incorporated or the façade in which the frame is placed. If the frame cannot hold the glass or the façade cannot hold the frame, the glass or the frame will fly inwards and there is still a risk of very serious injury. This means the shattering effect must also apply to the frame and the façade that supports it.

A window frame or façade with mullions and transoms is a complex product with glazing beads, sealant, joints, hinges and anchors. The weakest link is decisive, and it is difficult to calculate which component this will be. In addition, there are countless design and size options. There are several options for assessing the window frame:

1. Various window frame suppliers have test results for explosion-resistant profile series. Sometimes the test results have an excess in terms of dimensions, spans and/or load, so that it is plausible that the solution can satisfy the project requirements. Testing standard window frames under a slightly increased load is also very interesting. This can be used to substantiate when no additional measures are necessary, and a safe solution can still be created.

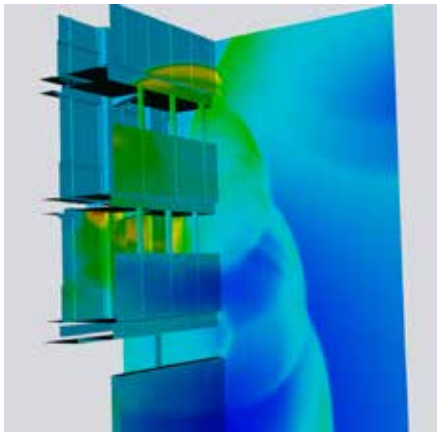

Figure 2. Pressure waves from an explosion on a gallery façade. CFD studies can be used to optimise the plot or building shape in order to reduce the load on the façade. In this case, the impact of a noise barrier on the gallery has been calculated.

2. In the case of complex shapes or large dimensions, the reference tests do not provide sufficient guidance. In that case, validated finite element calculations can be made on the basis of the above tests. These can be extrapolated to the project solutions. This is highly specialized work.

A PRACTICAL APPROACH

It is technically possible to install blast proof glazing in sound window frames and facades. However, if additional measures are required, this comes at a price. To avoid unpleasant surprises in a project, it is advisable to address this issue before the tender process.

1. Initiation phase
The safest option is to avoid placing highly vulnerable building functions in an explosion regulations area, but rather industry or storage.

2. SO/VO phase
• Divide the plot intelligently and place parking facilities or storage closer to the source and glass facades further away from the source. Use greenery to mitigate the impact of the explosion.
• Pay attention to the shape of the building. Niches, overhangs or narrow passageways amplify the explosion. Curved shapes are more favourable than rectangular ones.
• Preferably place the entrance on the leeward side.

3. DO phase
• Design integrally: buildings in areas subject to explosion regulations almost always have high noise levels. Soundproof glass, secondary glazing, gallery screens or second-skin facades provide additional explosion safety. Fall-through-proof and injury-proof glass also help to minimize the shattering effect of the glass. In some cases, requirements other than the shattering effect may even be decisive!
• Use reference tests to make window frame choices.
• Work out the substantiation of blast proof glazing for the tender.

4. Implementation
• Explosion-proof window frames and facades sometimes require additional measures. These are not always visible but do require attention during implementation. ■

Table 1. GSA/ISC Performance Conditions for Window System Response.

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.

Figure 3. Assessment method table GSA-TS01-2003 as developed by the U.S. General Service Administration and the Interagency Security Committee of the U.S. Department of Homeland Security.

Semester Abroad in Graz, Austria

Author
Tom Stuth

Hello everyone my name is Tom and I am currently spending an exchange semester at the Technical university in Graz, Austria. I would like to tell you all a bit about my experiences and dive a bit deeper in how I experienced research to be different here compared to at the TU/e.

Before even looking at the options, I already knew that I wanted to go to a German speaking country which left me with about 14 possible universities. It was surprisingly hard to determine whether a university also thought BPS courses. I had to sift through both Architecture and Civil Engineering programs since BPS internationally tends to fit between these I learned. Very interesting since at home I would never say I'm in Civil Engineering, but here I find that that is sometimes the easiest way to quickly describe what I roughly study. The TU Graz came out as the most fitting and interesting choice in the end.

Figure 1. Me with a bunch of international friends enjoying a day trip in Maribor

I am (already) about halfway through my time here, and enjoying it a lot. It has been surprisingly easy to make friends and I have been enjoying many activities that we don't get to do at home like skiing and hiking. The city is very similar to Eindhoven in size, but in style much more traditional which I am also enjoying. The same goes for the university. Unlike the TU/e which has a very defined separate campus, the TU Graz has 3 smaller campuses spread through a part of the city. I spent most of my time at the 'Alte Technik' campus where the traditional engineering like architecture and civil engineering are taught. Here you will also find the most traditional university buildings. Since we don't have these at the TU/e I have really enjoyed studying in these spaces, however also noted that it comes with negatives.

Figure 2. Main Building at the 'Alte Technik' campus. This is where the 'geoscience' labs are located

As one of my courses I am taking a Master project in a similar way we have them at home. For this project I am doing research on carbonation so I also get to do a little bit of lab work. Some of the labs are situated in these older buildings which I have found very interesting. To fit these labs the small traditional styled rooms had to be transitioned into high tech labs. It is a very cool atmosphere for doing research, but definitely has its issues. For example, to get into the main lab area you have to walk a long way around the building where the entrance is. Next to that half of the lab areas are on another floor which means walking this entire extra lap every time you need to switch between rooms. I learned that this means everyone simply uses a fire exit, however this leads you directly into a space next to the high temperature ovens. This thought me that some creative solutions are required to deal with the efficiency and safety when you transform a building like this to a modern lab, luckily they definitely have these.

Figure 3. Lab spaces crammed into a building from 1888

I would say that experiences like these are the most valuable in an exchange. You get to see how research is done differently in other places, the same goes for a lot of my other courses. However to be completely honest the things I have enjoyed most are of course the social aspects of the experience, and that would be the main reason why I can recommend anyone who gets the chance to do something similar. I will finish of by saying that I am looking forward to seeing you all again in July! ■

Figure 4. Panorama view of Graz

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Food Science Centre Wageningen: An Ambitious and Highly Sustainable Landmark From a Building Physics Perspective

Author
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Nelissen Ingenieursbureau

On the Wageningen campus, the high end research complex Food Science Centre has been realized, which accommodates Flora Food R&D B.V. Nelissen ingenieursbureau was engaged as building physics and sustainability (BREEAM) consultant and additionally contributed substantially in the field of acoustics.

The ambition of the client and design team went beyond mere compliance with the Dutch Building Decree. The project was developed using BREEAM NL New Construction (BRL 2014 v2.0) as the sustainability framework and set very high targets for, among other aspects, energy efficiency, material use, water conservation and health & comfort. The sustainability ambition of the client aligns well with the CO_2 Commitment 1,7 °C, a joint initiative of engineering and consultancy firms in the building sec-tor to reduce CO_2 emissions in the built environment.

From a building physics perspective, the Food Science Centre is particularly interesting with regard to:

- the building envelope and its thermal performance;
- daylight access, views and indoor climate;
- acoustic performance (internal and external);
- the BREEAM Outstanding criteria as an integrated sustainability framework.

The most important technical themes and design choices are outlined below.

ARCHITECTURAL DESIGN AND FRAMEWORK

The building accommodates offices, laboratory spaces, various kitchens, a restaurant and the Pilot Plant. It consists of two main volumes: one housing the Pilot Plant and the other containing the re-maining functions. Within the complex, researchers, scientists and chefs collaborate on the food supply of the future; the programme therefore includes office areas, R&D zones and a test kitchen.

Figure 1. Food Science Centre Wageningen, Fokkema & Partners Architecten,by Stijn Poelstra

Figure 2. Top view Food Science Centre Wageningen, Fokkema & Partners Architecten, by Stijn Poelstra

The primary load bearing structure consists of steel beams and columns with precast concrete floor slabs. The aluminium façade is a pronounced eye catcher and is wrapped in a timber exoskeleton with integrated planting.

BREEAM *OUTSTANDING* CERTIFICATION PROCESS

Performance requirements for building physics and sustainability were laid down in a detailed performance specification. A key element was the targeted BREEAM Outstanding certification. BREEAM (Building Research Establishment's Environmental Assessment Method) is an international certification method used to quantify the level of integral sustainability of buildings, with Outstanding representing the highest measurable sustainability score for a building. For successful BREEAM certification it was essential that, throughout all project phases including construction, systematic checks were carried out against the relevant standards, requirements and BREEAM credits.

The main principles in this respect were:

- Continuity of performance: the performance levels established in calculations and BREEAM credits must demonstrably be maintained through to completion.

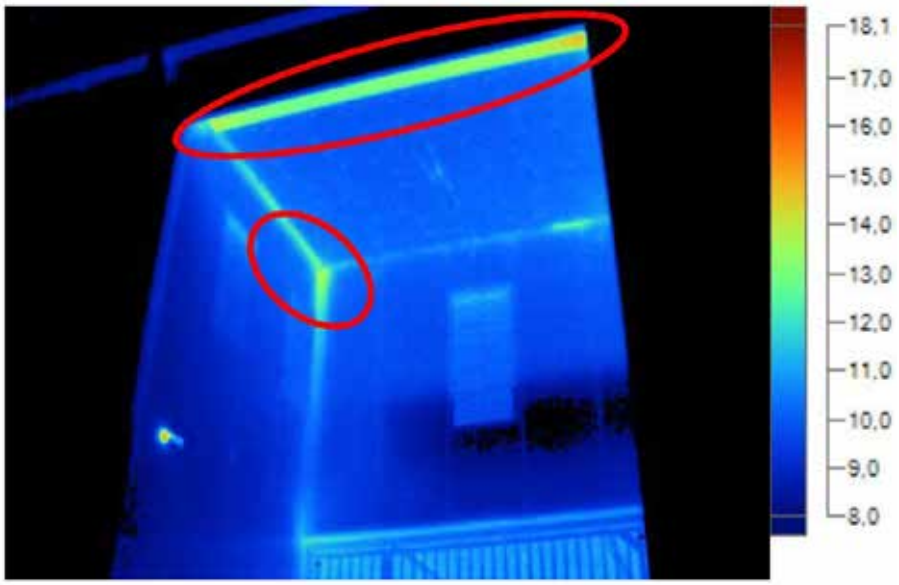

Figure 3. Thermographic inspection details

• Equivalence: alternative materials or details may not negatively affect the calculated thermal, acoustic or fire safety performance.
• Verification: post completion verification through measurements (including acoustics) and additional calculations wherever design choices were modified.

AN ENERGY-EFFICIENT BUILDING: ENERGY CONCEPT AND THERMAL ENVELOPE

At Nelissen ingenieursbureau, the overarching aim is always to realize buildings that are sustainable, comfortable, safe and healthy working environments. A low energy demand and a highly performant thermal envelope are key to this ambition. In technical terms, the following aspects played an im-portant role:

Optimisation of Rc- and U-values

The thermal resistance (Rc-values) of roofs, façades and floors was tuned to achieve a low heating demand, while also accounting for practical feasibility, such as structural depth, detailing and construction costs. Thermal bridges at connections between façade elements and at anchors were assessed, enabling a realistic representation of actual heat flows in the energy performance calculations.

Thermal detailing and airtightness

For critical junctions (façade–roof, façade–floor, window–façade) detailed thermal calculations were carried out, with explicit attention to linear thermal transmittances (Ψ-values) and airtightness. To fur-ther strengthen quality assurance, a building-wide air tightness test (blower door test) was performed, supplemented with infrared thermographic inspections to detect potential deficiencies in the executed work. Close collaboration with the contractor was essential and proved decisive for the successful implementation of these aspects.

Coupling with renewable energy generation

Multiple scenarios were evaluated, combining various configurations of solar panels, ATES (aquifer thermal energy storage) and other energy sources. Their impact on overall energy performance and CO_2 emissions was quantified, directly informing investment decisions.

These calculations were based on UNIEC software that calculates and analyses the energy performance and sustainability of buildings. It determines energy demand, heat loss, insulation performance, installation efficiency and overall compliance with energy and building regulations. Every modification in façade ratio, glazing and frame specification or building services concept feeds back into the energy performance and BREEAM score.

OPTIMAL COMFORT FOR DIVERSE USER GROUPS

Daylight, views and visual comfort

Due to the targeted BREEAM certification, the requirements for daylight access were significantly more stringent than the minimum legal standards. The design goal was to achieve a minimum daylight factor of 3% at the workstations. The daylight factor represents a ratio that indicates, for a specific point in a building, how the daylight illuminance there relates to the illuminance in the open field under an overcast sky. Daylight simulations were conducted throughout the design process to verify and refine compliance with this target. Key design parameters included:

• Façade geometry and orientation.
To meet the BREEAM credit HEA 01 (Daylighting), the position and dimensions of façade openings were optimized per façade orientation (north/south/east/west) to ensure sufficient daylight penetration deep into the floor plate. At the same time, excessive solar gains and the associated cooling demand needed to be prevented; for this reason a louvred façade system was adopted.

• Role of the fit out
The final fit out (partitions, cabinets, laboratory set ups) daylight admission can be substantially reduced. Therefore, daylight factors were recalculated in the fit out phase, even though the legal framework does not explicitly require consideration of the fit out with regard to daylight.

• Transparent versus opaque elements
In laboratories and rooms with specific privacy or safety requirements, a careful balance was sought between daylight access, visual connection and screening.

In addition to the quantity of daylight, its qualitative aspects were also important, such as providing views out and avoiding glare. BREEAM credit HEA 02 (View) specifies, among other aspects, requirements for sightlines from relevant workstations to the outside and a minimum variety in the view (including horizon, sky, greenery/built environment). To this end, sightlines and obstacle heights were analysed on the basis of 3D models.

Figure 4. Louvred facade system, Fokkema & Partners Architecten, by Stijn Poelstra

Throughout the design, an integrated assessment was made as to whether "more daylight" (e.g. more glazing or a higher visible light transmittance) is truly beneficial if it simultaneously leads to higher cooling loads or visual discomfort elsewhere.

Figure 5. Transparant and opaque facade, Fokkema & Partners Architecten, by Stijn Poelstra

Sound insulation, room acoustics and environmental noise

The building accommodates a wide range of space types: offices, meeting rooms, research spaces and potential production areas. For BREEAM credit HEA 13 (Acoustic Performance), requirements were defined for:

- airborne sound insulation between, for example, offices, meeting rooms and circulation areas;
- impact sound insulation where intermediate floors are subject to footfall;
- background noise levels from building services.

Nelissen ingenieursbureau performed calculations for critical partitions based on their build up (mass, cavity, resiliently mounted linings, etc.) and connection details, explicitly considering:

- continuous versus discontinuous suspended ceilings;
- flanking transmission via façades and corridor zones;
- openings and penetrations (service risers, shafts).

The calculated values were subsequently verified by on site measurements at completion (in accordance with the relevant ISO series for sound insulation). This approach ensures that the calculation models correspond well with the realised performance in practice.

MATERIALS AND EMISSIONS

Under the BREEAM MAT and HEA categories, choices were made that address both environmental impact and indoor air quality:

- MAT 1 & MAT 5: focus on materials with a low environmental impact and responsible sourcing (chain-of-custody certification).

- HEA 9 VOC emissions: finishing materials (flooring, paints, ceiling tiles) must comply with strict emission classes to limit volatile organic compound emissions. For the fit-out, these requirements were explicitly specified per material type.

Extensive calculations were carried out for the Dutch Environmental Performance of Buildings indicator (Milieuprestatie Gebouwen, MPG). The MPG assessments were used to quantify the total environmental burden at building level (in €/m² GFA·year) and to compare design variants. Life cycle assessment (LCA) data from the Dutch National Environmental Database and product-specific MRPI information were applied, ensuring consistency with national regulations and assessment frameworks.

Figure 6. Sound insulation and sound absorption. Fokkema & Partners Architecten, by Bram Vreugdenhil

Figure 7. Section sustainable solutions, Fokkema & Partners Architecten

Specific variants that were evaluated include different façade and roof build-ups, floor structures and finish packages. By comparing the environmental cost indicator (MKI) values of alternatives, design decisions could be based not only on technical performance (thermal, acoustic, fire safety) but also explicitly on life-cycle environmental impact.

The link between the MPG results and BREEAM credit MAT 1 (materials with low environmental impact) ensured that the same LCA-based substantiation could be used efficiently in both the statutory and voluntary sustainability frameworks. This is an illustrative example of how LCA/MPG analyses are increasingly becoming an integral part of the building physics design process: material choices are no longer guided solely by U-values, mass or cost, but explicitly also by their environmental profile over the full life cycle.

FROM THEORY TO PRACTICE: COMISSIONING AND HANDOVER

The role of a building physicist does not end with performing calculations. It is precisely the translation to detailing, execution and in use verification that makes the discipline relevant and tangible. A key aspect is how the "paper" performance is secured in the completed building, for example through systematic commissioning of the building services. Moreover, empirical verification remains essential: blower door tests, thermographic inspections, acoustic measurements and comfort measurements were all conducted to validate the calculated performance. The resulting insights are, in turn, applied in subsequent projects.

LESSONS LEARNED

The Food Science Centre provides an instructive case study for understanding how energy, comfort, moisture, acoustics and sustainability simultaneously influence design decisions. The project also illustrates that BREEAM is not merely a labelling system, but a design and process tool that requires systematic substantiation and verification.

We were surprised by how well the parties involved in this project were able to adapt to non-standard solutions that improved sustainability. One example was the use of materials that did not yet have the appropriate BREEAM certificates at the start of the project, but did have them upon completion as a result of targeted efforts. This requires a shared commitment to the sustainability goals and maximum effort from all parties to achieve a successful outcome.

We have seen that building physics is not a collection of isolated calculations, but an integrated design discipline conducted in close collaboration with the architect, services engineer, contractor and client. For us it is about guiding our clients towards smart sustainable solutions for people in building.

This project was realized in close collaboration with Fokkema & Partners, Van Wijnen Arnhem, Unica Building Projects and the wider project team. The BREEAM expert role was fulfilled by Iris Wijsman of Nelissen ingenieursbureau, and the project was assessed by Albert Jan Vermeulen of MAT25. ■


BREEAM NL

Nieuwbouw en Renovatie Oplevercertificaat

Hiermee wordt verklaard dat:

Upfield Food Science Centre
te Wageningen

BREEAM NL

is beoordeeld op basis van het schema:
Nieuwbouw en Renovatie Opleverfase Bespoke Upfield 2014 v2 B

door een BREEAM-NL Assessor voor:
Upfield

en een score heeft behaald van:
88,49%

Certificaatnummer: 1046-NBP-2014

31 januari 2024
Afgiftedatum

Albert-Jan Vermeulen
BREEAM NL Assessor

MAT25
Examenkundende organisatie

dr. Annemarie van Doorn, Dutch Green Building Council

Figure 8. BREEAM Certificate

Illustrating the Impact of Wear Position on the Performance of Wearable Light Sensors

Author
ir. S.W. (Sietse) de Vries

INTRODUCTION

The relatively recent discovery of the human intrinsically photosensitive retinal ganglion cells and their implications for health and well-being [1], has given an ever increasing prominence to the assessment of indoor lighting in terms of personal light exposure (PLE). Using dosimeters (small wearable light sensors), PLE data can be collected and related to measures of human physiology and well-being. Examples include studies using dosimeters to examine the (causal) relationship between PLE and physiological and behavioral indicators associated with NIF effects such as alertness, sleep, and mood, and to assess the impact of PLE on myopia. Beyond research applications, dosimeters are valuable in practice, as PLE data can be used to assess actual lighting conditions in buildings and to evaluate their potential to support NIF effects.

In these contexts, the physiologically relevant light exposure is at the eye. However, primarily for user comfort, dosimeters are often worn elsewhere on the body, typically on the chest or wrist [2]. The validity of using such proxy positions to measure eye-level light exposure has been a subject of ongoing debate for the last few decades, with the earliest study reported in 1983 [3]. Since then, multiple studies have sought to address this issue by comparing dosimeter measurements taken on the body and at the eye [4-14]. However, the reported correlations and discrepancies between body-worn and eye-level measurements vary across studies. Generally, these studies suggest that measurements from chest-worn dosimeters approximate eye-level light exposure more closely than those from wrist-worn devices [6,12-14], although this finding is not observed across all studies [11].

A primary reason for the competing claims in these studies is that most of them were conducted under naturalistic (real-world) conditions, rather than in controlled environments. As a result, the types of illumination fields under which the measurements were performed, as well as the typical activities (i.e. postures) of their subjects, varied across studies. Depending on these contextual factors, the amount of light measured at a certain position on the body can differ considerably [8, 12]. For example, under a relatively uniform illumination field, unobstructed dosimeters at different positions on the body tend to measure similar light levels, even when their orientations vary substantially. In contrast, under directional illumination, such as that produced by overhead luminaires in offices, small differences in the orientation of the dosimeter can lead to large variations in the measured illumination.

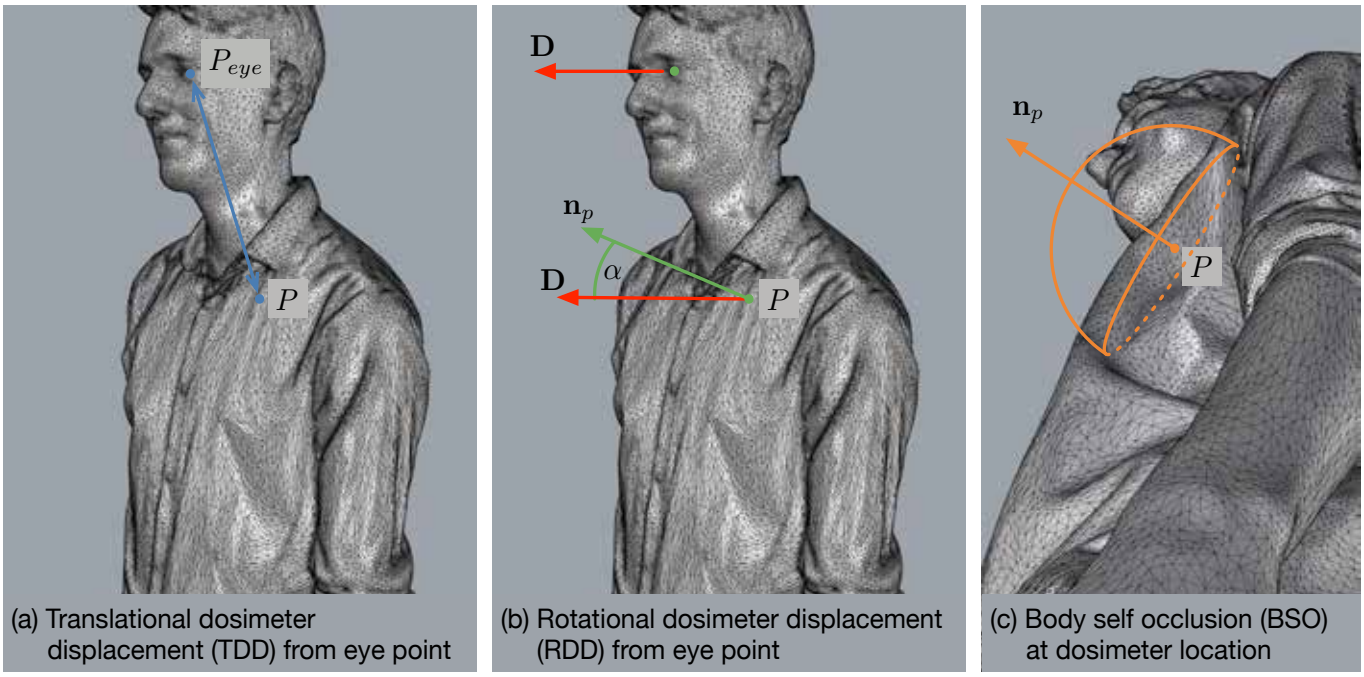

Figure 1. Three in-situ factors impacting dosimeter performance. The a) translational dosimeter displacement (TDD), b) rotational dosimeter displacement (RDD), and c) body self occlusion (BSO) are illustrated for a dosimeter at position P with sensor normal n_p, relative to an 'ideal' dosimeter at the eye point (P_{eye}) with view direction (normal) D.

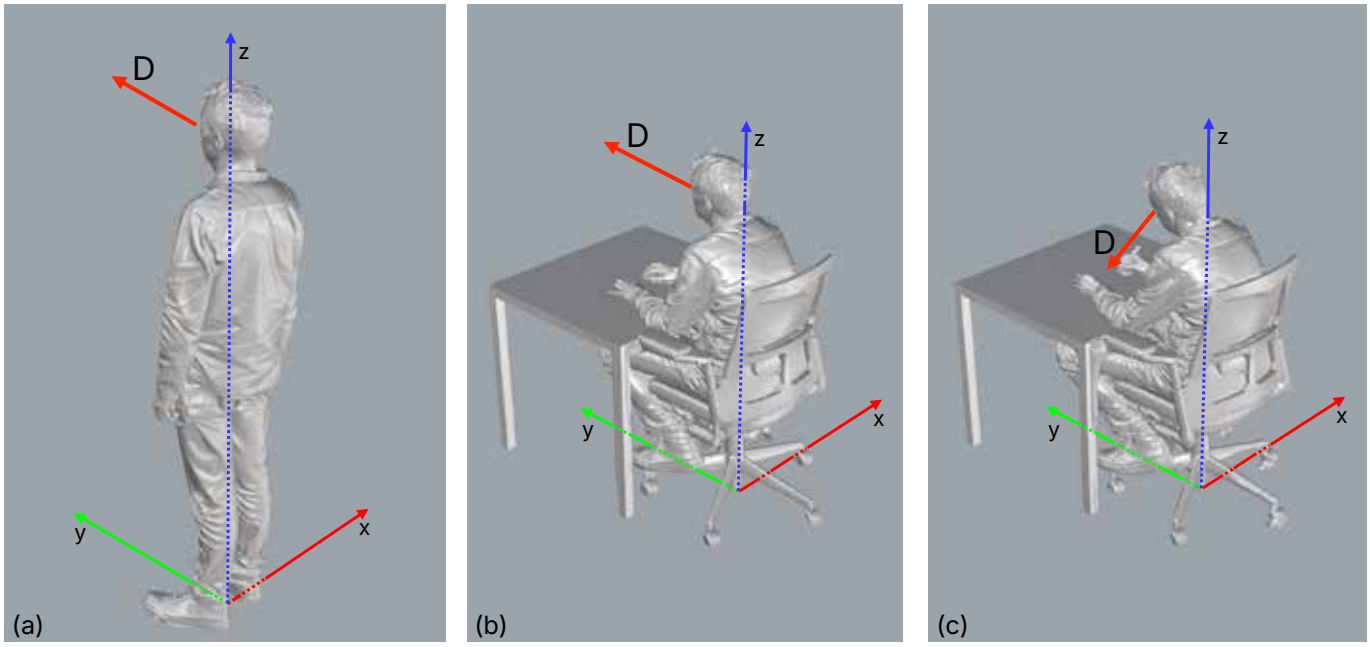

Figure 2. 3D subject model in three postures. All subjects were 3D scanned while a) standing, b) looking at a screen while seated (screen-facing), and c) writing while seated (desk-facing).

Given these challenges, alternative approaches are needed to better understand the validity of body-worn dosimeters for measuring eye-level light exposure. To this end, we introduce three factors (Figure 1) that are expected to affect the performance of bodyworn dosimeters. To be a reliable proxy for measurements taken at the unobstructed eye, i.e. measuring just in front of the eye, a worn dosimeter should:

i. Not be placed too far from the eye, i.e. limited translational dosimeter displacement (TDD).
ii. Not have the sensor normal (the center of the sensor's field of view) facing in too different a direction from the subject's view, i.e. limited rotational dosimeter displacement (RDD).
iii. Not be positioned such that the sensor's field of view is obstructed by the subject's own body, i.e. limited body self occlusion (BSO).

METHODS

A hybrid measurement-simulation approach was developed to quantify the magnitude and distribution of TDD, RDD, and BSO factors across an individual's body. Firstly, detailed geometrical models of twelve subjects in three postures (Figure 2) were acquired using a handheld 3D scanning technique. Subsequently, an image-based ray-tracing approach was used to compute each of the three factors across the body. Results are presented as renderings of the subject where each pixel is shaded using false color to indicate the magnitude of the particular factor at that point on the body. By applying illustrative limiting criteria to each of the three factors, we demonstrate how the method can be used to identify regions on the body where each factor is minimized. All simulations were conducted using Radiance v6.0a.

For each subject (in three postures), we generated a false-color image of TDD, RDD, and BSO factors using the magnitude of each factor as the scale. TDD was calculated as the Euclidean distance between each point on the body and the eyes and RDD as the difference in (body) surface normal relative to the view direction. BSO was determined by simulating the irradiance at each point on the body under an isotropic uniform illumination field. Any point that does not experience any self-shading corresponds to a BSO of 0%, while a point completely obstructed by the body corresponds to a BSO of 100%. Additionally, the theoretically most reliable dosimeter positions were illustrated by combining the results from these three factors and applying conditional thresholds. While the selected thresholds are arbitrary, they are intended to illustrate plausible criteria.

RESULTS AND DISCUSSION

The magnitudes of the TDD, RDD, and BSO factors, and the body surface areas meeting the conditional thresholds, are shown in Figure 3 for five seated subjects looking at a screen,

Figure 3. Dispersion of translational dosimeter displacement (TDD), rotational dosimeter displacement (RDD), and body self occlusion (BSO) factors impacting dosimeter performance on seated, screen-facing subjects.

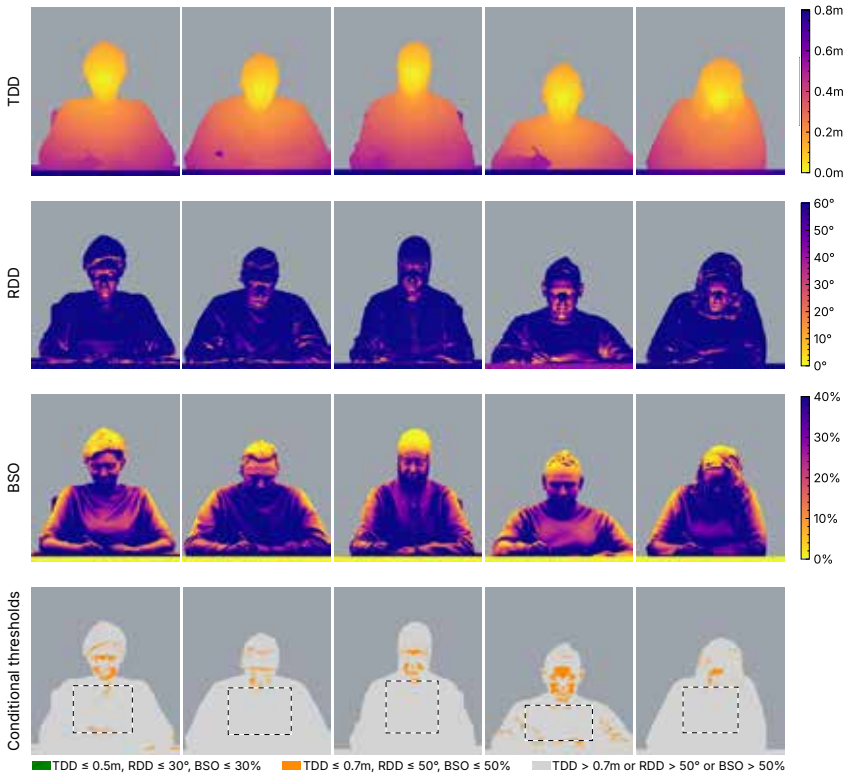

Figure 4. Dispersion of translational dosimeter displacement (TDD), rotational dosimeter displacement (RDD), and body self occlusion (BSO) factors impacting dosimeter performance on seated, desk-facing subjects.

and in Figure 4 for the same subjects while writing. The results for the standing posture and all subjects are presented in the journal paper describing this work [15].

These images provide visual means for identifying dosimeter positions with the smallest divergence from the eye. The main takeaway is relatively straightforward: even small shifts in dosimeter placement can lead to considerable variations in these three factors. Hence, the dosimeter position should be selected with care to minimize these factors.

For all three postures, the TDD remains stable across most subjects, as the distance between a dosimeter on the body and the eyes falls within a similar range. Only for subjects that are rather tall, larger TDD can be present. For the RDD and BSO factors, a distinction can be made between two types of postures: those in which the orientation of the torso is largely aligned with the view direction and those in which it is not. In the standing and seated, screen-facing postures, RDD values on the body tend to be limited, with some variations attributable to body morphology and gender. Notable deviations are found at the edges of garments, e.g. a shirt's placket. BSO is most pronounced in the regions under the chin and arms. For seated, desk-facing subjects, who were bent slightly forward and looked downward toward the desk, substantial RDD is present on the chest, as well as BSO by the head, torso, and arms. This suggests that when subjects engage in activities that involve frequent downward gaze, such as reading or writing at a desk, it may be more appropriate to position the dosimeter on the head rather than on the chest.

The degree to which the combined effect of TDD, RDD, and BSO causes body-worn dosimeter (irradiance) measurements to deviate from that at the eye will depend on the particular characteristics of the illumination field around the subject. In our follow-on study [16], we examine how different indoor illumination fields impact dosimeter measurements and demonstrate that the RDD is the main factor causing deviations relative to eye-level illuminance measurements. ■

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Sudoku

Author
Yenthe Smienk

The goal of Sudoku is to fill a 9x9 grid with numbers so that each row, column, and 3x3 section contains the numbers 1 through 9 exactly once. You rely entirely on logic and process of elimination; no math, guessing, or arithmetic is ever required to solve the puzzle. Good luck! ■

		8		9		1	4	5
7		2						
		5		3				
3					9	4		
				5		3		7
							2	
		6	2					
				1	4	9		
	1						7	

LogiKwis

Author
Yenthe Smienk

Logic puzzles are games where you find the right answers by using clues and facts, never by guessing. Each puzzle has only one correct answer because every item can only pair up with one other item. For example, if you figure out that Mollier lives in the blue house, nobody else can live in that house, and Mollier cannot live anywhere else. You can also connect clues together; if Mollier lives in the blue house, and the blue house is on Main Street, you instantly know that Mollier lives on Main Street. Use the clues to correctly fill in the grid. Good luck! ■

Clues:

1. The combined age of the Haskoning speaker and the Sweco representative is 82. One of them delivers the presentation on Building Lighting, and importantly, neither of them is scheduled for the May or June slots.
2. The expert discussing Building Materials is exactly 5 years older than the expert covering Building Acoustics. Additionally, the Acoustics presentation is the very next one scheduled in the year after Sweco's presentation.
3. Unica's speaker is older than the presenter covering Building Physics, but younger than Klictet's representative. You'll also find that Unica's presentation takes place later in the calendar year than the Building Physics one.
4. Nelissen's representative presents earlier in the year than the Building Performance speaker, but later in the year than the presentation on Building Physics.
5. The Building Lighting expert is younger than the Building Physics expert. Furthermore, the May slot is reserved for Building Materials, and the age difference between the May and June speakers perfectly matches the age difference between the October and February speakers.

		Age					Subject					Month				
		40	42	45	48	50	Building Lighting	Building Materials	Building Acoustics	Building Performance	Building Physics	October	December	February	May	June
Speaker	Unica															
	Nelissen															
	Haskoning															
	Klictet															
	Sweco															
Month	October															
	December															
	February															
	May															
	June															
Subject	Building Lighting															
	Building Materials															
	Building Acoustics															
	Building Performance															
	Building Physics															

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