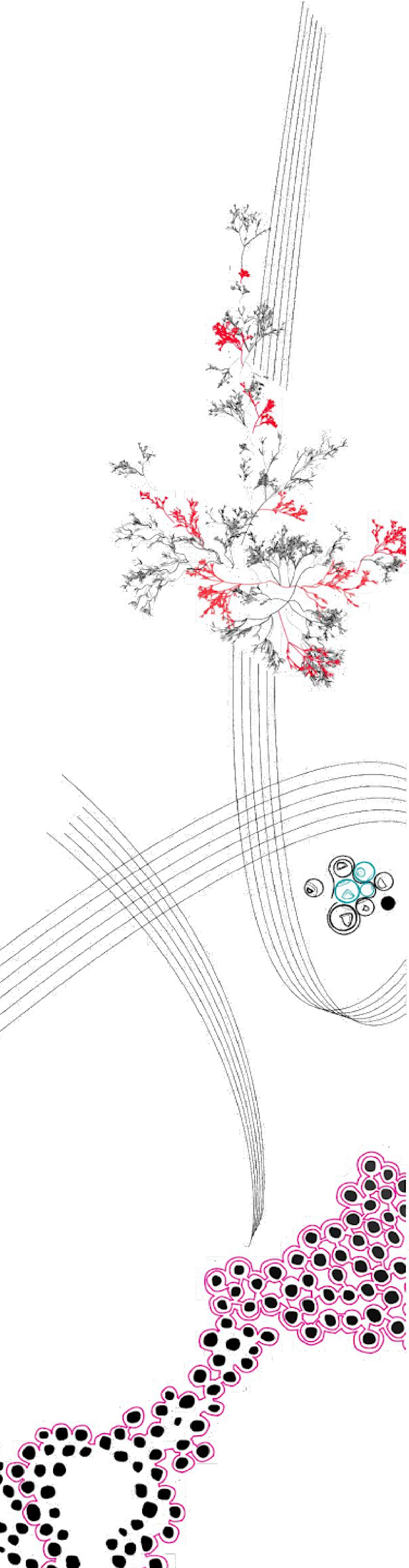

Exploring Uncertainty Management in Engineering Design Teams in a CAD-enhanced Learning Environment

Master Thesis

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Abstract

Background: This thesis explores the dynamics of uncertainty management in collaborative engineering design projects among university students, utilizing a Computer-Aided Design (CAD) tool, Energy3D. The study extends existing literature by delving into the strategies students adopt to manage task-related and social uncertainties in a CAD environment, aiming to contribute to instructional design and enhance collaborative problem-solving skills. **Objective:** The study aims to investigate how university students navigate and manage uncertainty while collaborating on CAD engineering tasks. With a focus on uncovering the types of uncertainties students face and the strategies they employ to manage these uncertainties, this research intends to enhance our understanding of collaborative problem-solving processes. **Method:** The study involved thirteen students, grouped into four teams, utilizing the Energy3D software for designing sustainable structures and assessing their energy performance. Data were collected through video documentation, individual SSRL radar charts, uncertainty-related questions, and concluding group interviews focused on the design process and uncertainty management. For this paper, the interaction data (from videos) was analyzed for markers of uncertainty and uncertainty management strategies using an existing coding scheme (Jordan & McDaniel, 2014). **Results:** Current findings suggest that students encounter various uncertainties, including technical challenges with CAD tools and gaps in scientific knowledge required for task completion. Strategies for managing these uncertainties ranged from reducing, maintaining, increasing, and ignoring uncertainty. Participating groups oscillated between these strategies in different ways. **Conclusion:** In conclusion, this study not only illuminates the complexities of managing uncertainty in collaborative CAD-enhanced learning environments but also offers valuable insights for enhancing educational practices. By understanding and leveraging the dynamics of uncertainty management, educators can foster more engaging, effective, and meaningful learning experiences for students. **Recommendations:** The study raises several open questions regarding the optimal ways to support students in managing uncertainties in CAD-enhanced collaborative learning environments. Future research may explore the impact of different instructional designs on students' ability to manage uncertainties and the potential for integrating specific tools or resources to facilitate this process.

Keywords: uncertainty, uncertainty management, design groups, energy3D, engineering, CAD

1 Introduction

In today's rapidly evolving market, the need and drive for innovation are more important than ever. Companies and institutions of all fields are constantly seeking ways to renew their strategies and push the boundaries of the current state of knowledge and understanding. This pursuit for advancement can be found in various sectors but is especially relevant in fields where challenging paradigms, exploring new boundaries, and stepping into unknown scenarios are the norm. These include fields such as development, engineering and industrial design, where long-term, complex projects rely on specialised knowledge and where processes are filled with uncertain aspects which can create challenges or opportunities for the projects (Nota & Aiello, 2014).

As highlighted before, engineering design is one of the fields which involves complex processes that are open-ended and often ill-structured. Because of the nature of tasks presented on the field, when problems arise, they are often presented with a lot of uncertainty such as unclear instructions and requirements or insufficient information (Seah et al., 2024). Uncertainty or ambiguity is not only present in such environments but as a fundamental aspect of human experience, uncertainty plays a crucial role in the shaping of the educational field and technology. In academic environments, uncertainty is typical as students strive to learn new information and skills, adopt new behaviours, and develop new understandings (Jordan, 2010). Thus, learning involves uncertainty, therefore it's critical to understand how pupils deal with it. Chan et al. (1997) suggest that deliberately introducing uncertainty can facilitate students in integrating novel concepts, values, and beliefs, while also fostering creative problem-solving (Audia and Goncalo, 2007; Cropley, 2006). The concept of uncertainty management has emerged from the understanding of how uncertainty could provide potential for an ongoing project.

When talking about uncertainty influencing learning outcomes and group dynamics, it is inevitable to understand the management of this phenomenon. According to the description by Walker et al. (2003), uncertainty management involves the understanding or the creation of meaning in situations where ambiguity is prevalent. When students often encounter new and complex problems, effective uncertainty management can potentially foster their deeper level understanding and initiate an innovative problem-solving strategy in collaborative learning environments (Walker et al., 2003). It is important to emphasise the crucial role of collaborative learning as a pedagogical approach to engineering and design tasks especially. The approach is grounded in the theory that learning is a social construct and that students learn more effectively when they are actively engaged in the process of learning together with other peers (Piaget, 1972).

Experiencing uncertainty is a common problem in collaborative engineering design projects. Tasks could include anything from comprehending math and scientific topics to using digital tools and assessing design concepts. Additionally, as university-level students meet foreign sociocultural practices and people with varied backgrounds, beliefs, motives, expectations, and values, engineering design projects are environments in which uncertainty is likely to arise from social difficulties. This can be defined as social uncertainty. The present study examines how four student groups engaged in an ill-structured collaborative engineering design project navigate both social and task uncertainty, by using a combination of observations, video recordings, and interviews to shed light on their management strategies.

Computer-aided design (CAD) engineering programs, such as Energy 3D in the current research project, can be used as facilitating tools for collaborative learning in engineering education, echoing the broader educational shift towards integrated STEM (science, technology, engineering, and mathematics) learning. These CAD-enabled engineering programs are known for their innovative, interactive properties where students can repeatedly scrutinise, calculate, compare, and analyse certain schemes and thus continuously manage and refine their understanding of a concept and their inherent uncertainties in a group. As highlighted by Johnson et al., (2015) and others, CAD environments enable learners to apply scientific inquiry, engineering design principles, mathematical reasoning, and technological skills synergistically, fostering a comprehensive understanding of complex concepts. Additionally, CAD programs allow students to visualise and manipulate design elements in real time which can further foster the understanding of complex concepts, enhance collaboration among peers and can offer a tangible means to visualize the impact of certain design choices. Moreover, there is empirical evidence suggesting that online collaborative design tools foster creativity and allow the development of diverse skills which can be used in the modern world. These include creative thinking and technical abilities which are essential when dealing with uncertainties arising from real-world problems (Dasgupta et al., 2019). Moreover, the utilization of CAD tools in educational settings mirrors the authentic practices of scientists and engineers who regularly integrate knowledge from different disciplines to inform their practice. This authenticity in learning experiences is vital for developing knowledge applicable in real-world contexts, enhancing the successful transfer and use of that knowledge, and engaging students in higher-order thinking skills.

1.1 Purpose and research questions

The current study aims to gain insight into how student groups manage uncertainty in the process of solving an engineering challenge in a computer-aided design environment. By identifying the types of uncertainties encountered and the strategies employed to manage these uncertainties, the study seeks to contribute to the development of instructional designs that better support collaborative learning and problem-solving in engineering education. With the ultimate aim to later, in further research contexts, construct a model of uncertainty management strategies which later can be used as a guideline to other experts or students when dealing with uncertainty. Such a model is currently lacking which could potentially help students manage uncertainty to their advantage in collaborative learning environments. Therefore, the objective of this thesis will be to generate the first steps towards creating an uncertainty management model which will be beneficial in the future of education when dealing with uncertainty in CAD-enabled collaborative engineering design projects. Based on this, to achieve the purpose of the study, the following research questions were formulated:

RQ1: What kind of uncertainty types were present when students were working on an ill-structured computer-aided engineering design task?

RQ2: What kind of strategies did students employ in order to manage their uncertainty?

RQ3: How did these uncertainties and their management within the group projects influence the final designs?

To answer these research questions, a non-systematic literature review is going to be conducted together with data gathering from student design groups in the form of a creative computer-aided design challenge. This study is an initial exploration of categorizing and synthesizing the strategies students employ to manage uncertainty. It serves as a first step for the subsequent development of a comprehensive model aimed at effectively addressing uncertainty in collaborative learning environments.

2 Theoretical framework

The following chapters investigate the theoretical background by proposing significant concepts and theories which are essential for the already introduced research direction which is being examined. Since the main focus of the research is to provide an overview of how to manage uncertainty in student design groups when working on a collaborative, ill-structured engineering design problem, the following chapters summarize the previous findings and existing literature and define key concepts connected to the researched topic. The purpose of this theoretical framework is to explain and support the argumentation of the current research study and to introduce the proposed hypotheses which will later be examined and answered with the help of data gathering.

2.1 Uncertainty

Uncertainty touches most aspects of life and is often mentioned in situations where a decision must be made, but the person who is supposed to make it is not sure how to proceed. Uncertainty is a term used in several fields according to Tannert et al. (2007), including economics, philosophy, finance, psychology, insurance, sociology, and information science. At the empirical level, uncertainty is an unavoidable companion of any measurement resulting in the combination of measurement errors and resolution limits of measuring instruments. At the social level, it can have strategic uses, such as privacy, secrecy or proprietary created and maintained by people. At the level of cognition, however, uncertainty emerges from the ambiguity and vagueness of natural language (Klir and Weirman, 1999). In the context of engineering projects specifically, the available literature is scarce which is the primary motivation of this thesis.

Uncertainty is a rather instantaneous and spontaneous feeling which can be relevant to relationships with individuals, tasks, the environment or to one’s self. These relationships and expressions of them could act as social cues and can influence social cognitive processes (Schubert, 2009; Schwarz & Clore, 2007; Afifi & Afifi, 2015). Research has shown that within collaborative learning environments and projects, peer interactions can influence social and task goals, motivational behaviour of participants, cognitive and affective behaviours and participation of students in the work (Jarvenoja & Jarvela, 2009; Vauras et al., 2008). Thus, when ambiguity or uncertainty is present in a collaborative environment, the task outcome can highly depend on the interactions and social cues present in the group dynamics. In academia, uncertainty is a common experience since students need to make sense of materials unfamiliar to them and have to participate in entirely new social settings (Jordan, 2010). Hence, research revealed that uncertainty, within the context of learning and academic achievements, can be sourced from the complexity, novelty, or unfamiliarity of the task (Herbst, 2003; Jordan, 2010;

Radinsky, 2008). One would think that because of the previously mentioned influential nature of uncertainty, it should be minimized or attempted to be eliminated as much as possible to help students gain knowledge. On the contrary, in some cases creating uncertainty facilitates learning by encouraging the students to rethink their current methods, values and concepts when solving a task or studying (reference needed). This is especially relevant when taking into consideration a task with a design or engineering nature (ref). In these cases, students can be nudged to think further, outside the box and come up with a creative problem solution which promotes their learning and innovative skills (Glanville, 2008).

Learning how to deal with ambiguity in engineering design projects, such as the current one, is crucial. This is due to the fact that in the duration of a task like this, students often encounter complex problems where they need to discover new scientific concepts, and technological tools or employ more advanced mathematical or physical knowledge. Engineering design tasks have uncertainty inherently since solving such a task involves a trial-error strategy, multiple paths and continuous redefining of the problem itself and its possibilities (Pressman, 2018). Because of the collaborative nature of engineering design tasks, not only these task-related ambiguities are present, but also socially generated uncertainty is present. These can include uncertain relationships among peers, their responsibilities and roles within the group and the possibilities to express themselves and be understood by their peers (Jordan & McDaniel, 2014).

2.2 Managing uncertainty

As established in previous paragraphs, uncertainty is present in everyday life, but managing it on different levels can sometimes be challenging for individuals. According to the findings, on the one hand, people experiencing uncertainty in a situation are most likely trying to find a strategy to reduce uncertainty. In some cases, on the other hand, individuals also try to manage ambiguity by ignoring it, maintaining its levels or, depending on the goals or beliefs of the individuals, purposefully choosing to increase uncertainty (Babrow & Matthias, 2009). In the context of education and collaborative learning, task uncertainty and intentional uncertainty generation could result in more effective brainstorming and new solutions for a task (Mueller et al., 2011). Thus, it is essential to note that in such contexts students must learn when and how to express and adapt their uncertainty depending on the social setting. The process of uncertainty management could potentially become effective when students engage with the material deeply and create meaningful cognitive connections (Kaur & Dasgupta, 2019).

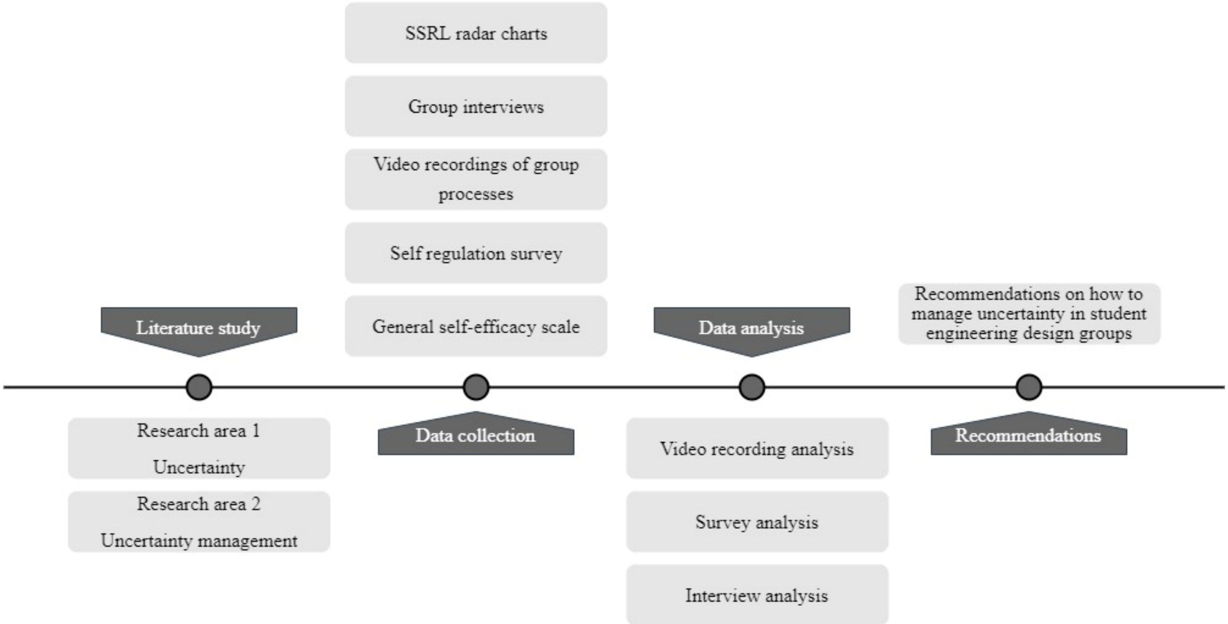
When it comes to CAD-enhanced collaborative learning environments where students need to depend on each other, not only on themselves to manage uncertainty, the research background is scarce. Jordan (2014) conducted multiple studies in which she explained how peer interactions influence uncertainty management during collaborative tasks. In her study together with McDaniel (2014), where elementary school children were working on robotics tasks, they revealed that peers' responses to uncertainty significantly influenced the teams' ability to manage uncertainty and solve the tasks. These findings suggest that instructional design should take peer influence and social dynamics into consideration when talking about uncertainty in collaborative learning environments (Jordan & McDaniel, 2014).

In 2015 Jordan extended these findings and explored the propensities for managing uncertainty. This study highlights the individual differences among students' engagement levels, perceptions, and attitudes towards uncertainty and how these can have an influence on collaborative design tasks. What can be concluded from such findings is that in order to manage uncertainty successfully in a collaborative setting, it is necessary to acknowledge the individual differences students or student groups can have. That is why it is important to create dialogue among students to support their uncertainty management strategies to facilitate the co-construction of knowledge and understanding (Chen, 2019). Thus, in a collaborative setting, promoting open communication and support is essential. Furthermore, Chen (2020) also clarified in a later study that it is not only crucial for students to learn how to manage their uncertainty, but it is also necessary for teachers to prepare to be able to navigate uncertainty in learning processes. Although these studies do not focus on CAD environments, they do highlight the most important aspects of managing uncertainty.

3 Method

This chapter will cover the methodology and techniques used for the thesis. This includes the rationale and supporting evidence for the literature review, data gathering, data processing, and suggestions. To be able to answer the posed research questions, the current study has been split into four main parts: literature research, data collection, data analysis and recommendations. The study employs both quantitative and qualitative data. The research approach can be seen in the visualization below (Figure 1). The team of researchers were made up of three female students, of whom two are bachelor Psychology students and one is an Educational Psychology master's student. A request to conduct this study was submitted to the Ethics Committee of the BMS faculty and shortly after submission, it was approved.

Figure 1
Research approach



3.1 Participants and recruitment

Thirteen current students or recent graduates of the University of Twente and Saxion University of Applied Sciences were recruited through convenience sampling. No specific criteria were applied during the recruitment. All participants volunteered to take part in the experiment. They were then allocated to one of the four design groups, consisting of 3 or 4 students each. The data of group 4 was decided to be left out of the analysis because it was not complete. Because of various technical issues, some parts of their recording were missing, thus their score is not complete.

3.2 Learning environment

A simulation-based engineering program called Energy3D is used to design green structures and power plants that use renewable energy sources to promote sustainable development. A realistic-looking structure can be rapidly drawn by users or imported from an existing CAD file, then superimposed on a map image (such as a lot map or Google Map), and its energy performance can be assessed for any given day and location. Energy3D can quickly produce heat maps (like infrared cameras) and time graphs (like data loggers) for in-depth analysis based on computational physics and meteorological data. Additionally, generative design, engineering optimization, and autonomous assessment are supported by artificial intelligence. When the design is finished, users may print it off, cut out the pieces, and assemble a real scale model with the help of Energy3D. The main purpose of Energy3D is to promote science and engineering education and training from middle schools to graduate institutions by offering a simulated environment for engineering design. It can also be used by experts as an entry-level energy modelling tool because of its realistic simulation results and user-friendly interfaces (Xie et al., 2018).

3.3 Procedure

At the commencement of the study, participants were instructed to organize themselves into groups of three or four. Each group was allocated to a pre-arranged workstation equipped with essential materials and tools for the experiment. These workstations were set up with a packet of materials for each participant, a laptop, a touchscreen device, an informational pamphlet detailing energy-saving and insulation strategies, and additional writing supplies. Participants had access to refreshments throughout the duration of the experiment. The activities of each group were documented using a 360° Kandao camera positioned centrally on the tables.

Following an introductory greeting by the research team, participants were required to complete and sign informed consent forms, available in appendix A. The forms necessitated the inclusion of participants' names, which were subsequently anonymized. Participants were then assigned unique codes (e.g., A1, A2, A3, etc.) to use on all documentation to maintain confidentiality throughout the data collection process. After the informed consent process, groups were given time to review the task instructions collectively and engage in a preliminary discussion.

Before initiating the primary task, participants completed a self-efficacy scale and the initial part of a regulation survey, assessing individual levels of self-regulation (refer to Appendices B & C). This gave the researchers an overview of the participants' individual thinking and goal orientation which could then later be observed and compared to their actual behaviour in the group. Following the collection of these documents, the groups commenced the first exercise. The task involved collaboratively designing a net-zero energy-efficient house using the Energy3D simulation program, adhering to specific construction and design criteria outlined in the appendix. The first exercise was allotted approximately 25 minutes for completion. Upon conclusion, participants individually completed SSRL (Self-Regulated Learning) radar charts (Appendix D) and responded to four questions regarding uncertainty within group dynamics. Participants were encouraged to express their emotions and thoughts freely regarding all parts of the assignment and group work in general. Additionally, participants were urged to perform reflective discussions once the SSRL charts were filled out after each round of challenges.

A brief intermission was allowed before the second task phase, wherein groups were tasked with revising the energy-efficient house design. In this phase, modifications to the foundational shape or size were restricted, yet the design was to be optimized within a fixed budget of €200,000 and completed within a 20–25-minute timeframe. Following this, the SSRL radar charts and uncertainty questions were revisited, mirroring the process of the first phase.

After another short break, the final phase required participants to refine their house designs, correcting any errors to achieve net-zero energy consumption, and ensuring compliance with all predetermined criteria within 10 minutes. The concluding documentation included the SSRL radar charts, the uncertainty questions, and the second part of the regulation survey. The data collection concluded with individual group interviews, focusing on their design process and uncertainty management techniques.

4 Data analysis

The analytical approach of this study was both inductive and interpretive, guided directly by the themes and insights identified in the literature review. In this context, inductive analysis refers to the process of identifying patterns, themes, and categories emerging directly from the data itself, without preconceived hypotheses, while interpretive analysis emphasizes understanding the meaning and implications of those patterns concerning the participants' experiences and perspectives within the engineering design task. After data collection and the transcription of the video and audio recordings, the coding program, Atlas.ti was employed to organize and analyse the files. The focus of the current research is on the strategies students employed in order to resolve their uncertainties during the engineering design task, the rest of the collected data, namely the self-efficacy scales, self-regulation surveys, and SSRL radar charts, were decided to be left out of the analysis. An interpretive analysis is necessary for this inquiry since the data is limited to the interactions of participants in a collaborative group setting and is often ambiguous. These interactions are not always solely verbal, but also nonverbal and often multiple things happen simultaneously which can express uncertainty and its management in the group. For example, one single comment or verbal expression may move the whole task forward or change the course of uncertainty.

The first step of the data analysis was to polish the transcripts of the four groups. This means that the transcripts were corrected, when necessary, by viewing and listening to them multiple times. This resulted in a more precise indication of pauses, hesitations, paralinguistics (e.g ‘huh’; ‘um’), sequence of turns and overlaps in talks in each transcription. When looking at uncertainty, small pauses, hesitations, and paralinguistics can convey meaning, therefore it is important that the recordings are carefully examined and transcribed. In the next step, the video recordings and transcriptions were skimmed through in order to identify and describe the scenarios where the design groups had issues and uncertainties and how they managed those situations. These identified episodes were then compared to the interviews, conducted after the group sessions, to search for evidence that students did experience uncertainty cognitively a socially in those situations. Additionally, students were also asked questions during the interviews about how they managed the uncertainties they faced. These statements were again compared to the events on the video recordings. Once these initial identifications of uncertainty and management strategies were noted, the data was coded using the coding scheme generated by Jordan and McDaniel (2014) which can be seen in Table 1 below.

Table 1

Strategies and categories for managing uncertainty (Jordan & McDaniel, 2014)

Reduce	Ignore	Maintain	Increase
Analyse issues	Keep going (persist, bluff)	Delay action, decision, or evaluation	Open the problem space
Test systematically	Avoid	Acknowledge	Purposefully seek multiple alternative action trajectories or opinions
Engage in trial-and-error experimentation	Dismiss (do not consider introduced uncertainty)	Express doubt	
Explain clearly	Blame		
Request information from group members			
Observe others			
Seek expert other			

Seek information from materials or texts	
Ask for confirmation	
Draw on past experience	
Seek consensus	
Refer to an authority figure	

5 Results

The following chapters are going to explain in detail what the findings of the study were, in order of the posed research questions. To ensure the trustworthiness of the data analysis, the coding was done by two researchers, both experienced in qualitative data analysis. To code the data, the strategies, and categories for managing uncertainty developed by Jordan & McDaniel (2014) were used (see above Table 1). Each transcript of the video recordings was then individually coded by both researchers according to the rubric and compared the degree of agreement. Throughout the coding process, the researchers would pause and discuss when there were any doubts or questions to eventually reach a consensus. Finally, the researchers reached an 88% inter-rater reliability agreement which is considered to be an acceptable rate (Shweta et al., 2015).

Throughout the CAD-enabled design project, there was a lot of uncertainty expressed in all four groups, but with discussions within groups and with the researchers on occasion, the groups were able to work through and resolve uncertainties. These uncertainties were mostly connected to the design optimization of the task and the students' scientific knowledge of the topic. In the following, there will be certain interactions highlighted as small episodes where it is shown how uncertainty issues were managed by each group to achieve their goals based on these interactions. These episodes did not occur at a constant rate for each group, but there were patterns of topics which appeared in multiple groups.

I. *What kind of uncertainty types were present when students were working on the computer-aided engineering design task?*

When analysing the video and audio recordings of the participant groups, there were four types of uncertainties identified in the current research setting. These included (a) design optimization issues – instances where students expressed doubts about the requirements they had to fulfil or about the design optimization in general; (b) lack of scientific knowledge – instances where students had problems with their lack of scientific knowledge necessary to optimise their design and fulfil the posed criteria in the task. These two uncertainty categories were mentioned by the students in the post-task interviews. In the following, there will be quotations from the participant groups in which they talk about their uncertainties based on these two types. The first example category entails instances where students expressed doubts about the requirements they had to fulfil or about the design optimization in general.

> *"Just with the time. That was also a constraint because it was always like we had okay, now we need to start. Let's just try, try, try. And then it is difficult."*

> *"Yeah. To make it, to make it look good. That was pretty challenging. Mostly because what we exactly wanted to do was sometimes a bit difficult to deal with. The, with the roof we were given. But eventually we did figure, figure it out."*

> *"Especially due to the time constraint, we just kind of stuck with the first good idea we had and moved on to the next thing because we had to keep moving."*

> *"I feel like the biggest problem in our group was probably understanding the assignment in different ways. So for example, when I thought, oh, it had to be livable, I didn't think that it meant, oh, it just has to be the minimum. It just has to be minimally humane, and he was like, I wanted it to be minimally humane to make sure that we could increase efficiency as much as possible. And you were also on his team. Yeah, it was unclear exactly how we would achieve the requirements of the exercise itself. So the ambiguity caused a little bit of confusion."*

> *"But some of the things we just haven't changed during the whole design process and I think that might be if we had more time, then we could have also focused on but does this really work? So, the freedom was something which created confusion."*

Next, when students had problems with their lack of scientific knowledge necessary to optimise their design and fulfil the posed criteria in the task, they expressed them the following way.

> *"And for example, I tried to then go deeper into what can we do? But uh, yeah, we I couldn't figure any more out from the technical side, from the pamphlet, for example."*

"I also feel because our knowledge was a bit low on the topic, we were doing a lot of trial error."

"You only had 20 minutes, yet you were given like a two-sided piece of paper with physics on it. And like all these, well, necessary yet maybe overly complicated concepts for the assignment at hand. So, I was like, okay, how are we going to implement all of these things within the given time? Yeah. Um, yeah. We, we just, I think confused whether to like, use that thing or like, understand that thing or just start building quickly."

"And I think the, um, the pamphlet gives you some basic information. Um, but the, the translation into to the program, like how would you use it? It's, um, it's a bit difficult because, um, you can say, hey there, there's a thing called solar radiation. Well, that's good to know, but how would you incorporate it into your house? Um. Like that. That transition is not told to you. So, um, I think we read the pamphlet and then didn't do anything with it."

Table 2
The types of uncertainties each group of students faced while working on the challenges and their frequency of occurrences

	Group 1	Group 2	Group 3	Totals
Design optimization issues	16	17	20	58
Lack of scientific knowledge	4	15	11	30
Totals	20	32	31	88

In the table above it is clearly visible that most frequently participant groups had ambiguity issues with the optimization of the design. Mostly group 3 struggled with such uncertainty. Uncertainty based on the participants' lack of scientific knowledge was only causing issues to the groups 30 times throughout the group distribution of occurrences. In this case, group 1 only had 4 instances and group 2 and 3 were the highest scoring with these challenges.

II. What kind of strategies did students employ in order to manage their uncertainty?

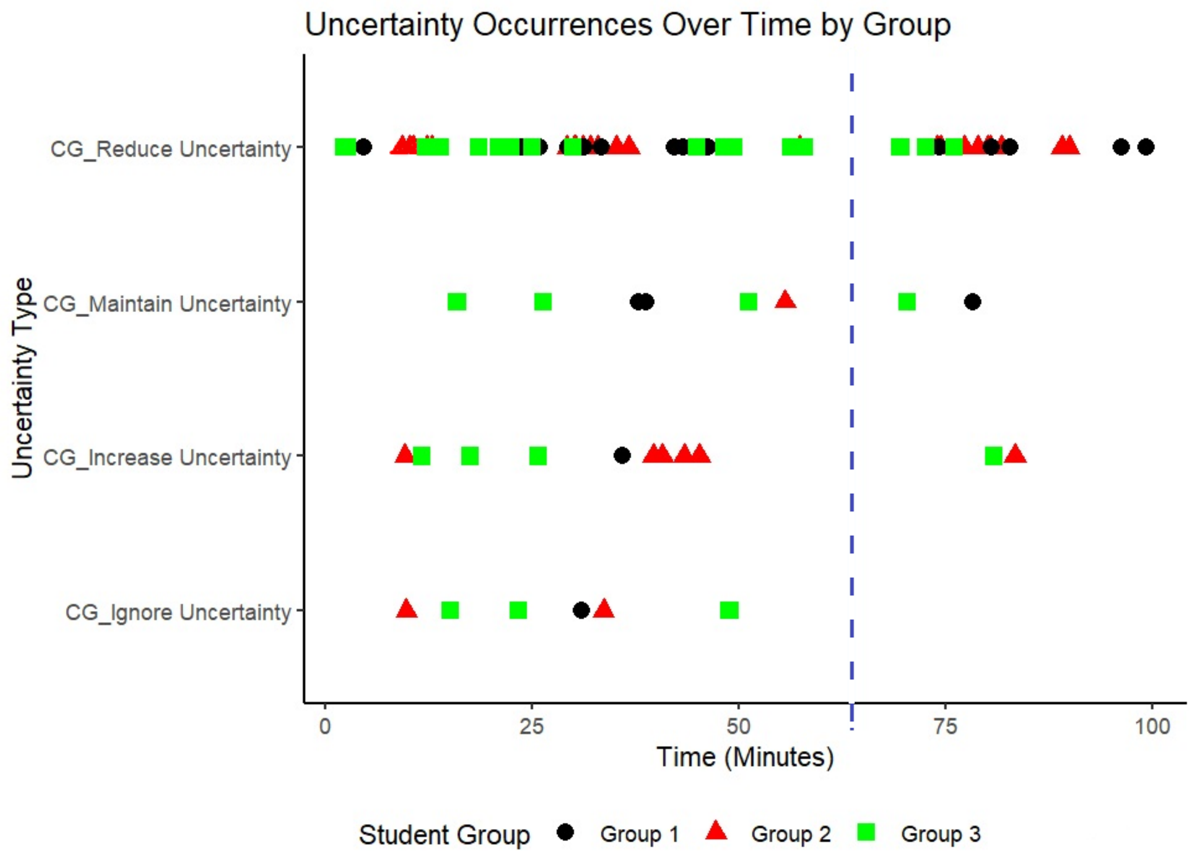
To gain a better understanding of the ways how university students manage their uncertainty while working in a CAD-enabled engineering design environment, the study employed a coding scheme developed by Jordan & McDaniel (2014) and according to these criteria, examined the ways students responded to uncertainty within their groups. In the table below the frequency of each uncertainty type can be seen regarding each participant group which is also visualized on a scatterplot in Figure 2.

Table 3
The ways each group of students responded to uncertainty and their frequency of occurrences

	Group 1	Group 2	Group 3	Totals
Ignore uncertainty	1	2	3	6
Increase uncertainty	1	6	4	12
Maintain uncertainty	3	1	4	9
Reduce uncertainty	15	23	20	61
Totals	20	32	31	88

As is seen in the table above (Table 2), all student groups mostly employed uncertainty management strategies to reduce their uncertainty at the given moment. To be exact, the student groups tried to reduce the levels of uncertainty 68 times in the course of the design process. The other three categories were much less popular choices among the participants. While attempting to increase and maintain the introduced uncertainty were used 13 and 12 times by all groups, the ignorance of it only happened 6 times overall. This data distribution can be translated as the students overall successfully recognized and attempted to reduce the uncertainty instead of ignoring it.

Figure 2
Uncertainty occurrences over the design process of the three student groups



As seen in the scatterplot above (Figure 2), the distribution of codes used over time varies per group. The most uncertainty occurrences over the time of the task were spotted in group 1. The scatterplot shows that most of the uncertainty occurred in all groups at the beginning of the design task in the first half of the recordings (before the dotted marking). This is attributed to the fact that the participants were unfamiliar with the CAD-enabled environment, and they engaged in more conversations about their doubts regarding it. In the second half of the task where the groups had to design the second house with slightly different criteria, there was again more uncertainty present because of the changed requirements. In the end, when the students were asked to refine their second design in order to meet the net-zero criterion, there was still some uncertainty about their design optimization, but visibly not as much as in the first two rounds, especially in the beginning.

The following episodes were highlighted from the transcripts to better understand what kind of strategies students employed and how they managed the uncertainty in the group design processes. In the first episode, a student tries to reduce his/her uncertainty by requesting information from the other group members. This conversation took place in Group 1. It was their first conversation as a group after a brief introduction. After this initial uncertainty, they went on by talking about the instructions written on the paper presented to them.

Excerpt 1:

> **P1:** So we can do changes to the house. We will see the effects also, **right?**
> **P2:** Yeah, I think so. This programme. Yeah. Um, I think this is it. *opening Energy3D on the laptop* And I think we can use this to build that house.
> **P1:** Also experiment a little bit, But I'm guessing if you make a decision, it doesn't mean we have to stick with it. We can still change, **right?**
> **P2:** No, I don't think. I don't think so. No.
> **P1:** Really?
> **P2:** No. It's… Ohh. Yeah. What you said that change doesn't stick. Yeah. That that does not.
> **P1:** Yeah, I'm okay with that because honestly I don't know all the answers. I'm also unsure…

In this interaction, P1 expressed doubts about how the program is going to work and how their decisions throughout the process might be changeable or not due to the program. Another student replied signalling that he/she did understand the concept of the program making the peer interaction seem to be successful in terms of uncertainty management. Implying from the final answer of the concerned participant, it is possible to conclude that he/she felt understood by the peer who responded and thus the uncertainty was resolved. Overall, it was a common response in peer interactions when one participant was experiencing uncertainty and the others were supportive without experiencing this uncertainty themselves. This created a space for equal participation and debate about the design processes without letting anyone feel insecure about their ambiguity.

In other cases, participants opened up about the ambiguity of the task by stating a problem and trying to see whether the others can offer a solution to it or not. These were the cases which belonged to the category of increasing the present uncertainty. The following episode from group 2 highlights a debate about the given budget. This conversation piece escalated from the instruction paper. When the students read the criteria for completing the task, one of them mentioned that the paper stated that 'the house should be beautiful'. This ignited the debate whether the budget is going to be enough to complete the task successfully or not. In this case, the student who raised the concern opened the problem space to increase uncertainty.

Excerpt 2:

P1: I mean, I'm going to be honest, **I don't think** a budget of 200k is going to cut the requirements of the house.

P3: No, that's simply nothing.

P2: No, you need like 200k for that. But is it 200k? Is it including the construction of the house? Or is the house already built?

P1: Yeah, I'm **confused**.

P3: Even the house already built for 400k.

P1: Like, renovating an old house. So one window is...

P4: Maybe the simulation gives us a very cheap price or something.

P2: Yeah, hopefully.

In this scenario, each participant increases the uncertainty by answering with just as much ambiguity as the other peers before. Thus, the unsureness of the participants is not resolved at the end of the interaction, just put aside with the hope of figuring it out at a later point in time. This kind of management strategy was mostly present at the beginning of the design tasks where students were still trying to experiment with what was possible and impossible in the CAD environment.

The next episode shows an example of when participants express their doubts about the design optimization of the house in order to adhere to the requirement of achieving a net-zero energy-efficient house. In this highlight, the students keep maintaining the ambiguity by debating about how the house should be shaped or where the rooms should face but cannot come to a consensus because of the present uncertainty. This episode is taken from the transcript of group 1.

Excerpt 3:

P1: That's what we make enough like, like so, so that multiple sites have the same … **I don't know**

P2: What do you mean?

P3: Like a diamond shape?

P1: Do you want to make now room room?

P2: No. What I want to I wanted to make like a rectangle like a triangle here so that the there's there's not really in north side and that there's always a side like

P2: I don't know as much as possible space facing South. So you can get as much solar stuff.

P1: But then you have like 2 walls facing north,

P2: Like like not not direct North but like northwestern, northeast.

Lastly, the least number of times were uncertainty not considered, but it did still happen for example in group 3, where one of the participants was concerned about the number of solar panels, but the other group members did not even take a moment to consider reassuring him in order to resolve the ambiguity. In this case, the student is very unsure about the solar panels, but the other group members are more concerned about the walls of the house, how that works in the program and completely ignore the introduced uncertainty. In this case the ambiguity was not resolved by the interaction among the peers.

Excerpt 4:

P3: Solar panels… how many or how are we going to do… ?

P1: Just like I think… Oh no…I think that's a it's a just a separate one.

P2: Do we first want to do the interior walls?

P3: Oh…

P2: What?

P1: Oh, so I think you should remain within the…

P2: Oh, yeah.

III. How did these uncertainties and their management within the group projects influence the final designs?

To answer the final research question, one group, namely group 2 was chosen to be analysed. This group was chosen because the conversations about the design optimization and the ambiguities regarding it were the most prominent and visibly translated in their final product as well. Next, there will be quotations of the group in which the participants express their ambiguity throughout the design process and how these conversations translated later in their design products. The first excerpt presented is a conversation piece which occurred before starting the actual design process, in the brainstorming phase. Because of the lack of scientific knowledge of the group, participants are analysing together the presented issue of the size of the windows, angle of the walls and how the sunlight influences the energy use of the house.

The strategy the group made use of is the reduction of the ambiguity which influenced their design in having one floor over two in the house design and an angled roof.

Excerpt 5:

P2: But then how does having large windows have a relation with maximum solar radiation?

P4: Isn't it for like solar panels? We want the angle of solar panels?

P2: I mean yeah but they have to talk about windows.

P4: Ah…I wasn't here yet.

P2: But then they mean the inside of the house or something. Or what**? I don't know…**What can you do to allow the maximum light into the house, through the windows?

P4: Yeah, like if the windows, this angle, there's more light coming in, **I guess.**

P2: Yeah.

P3: It's stronger, yeah.

P2: So what would that imply? That you have like non-vertical walls. Kill the wall.

P4: Yeah. Maybe.

P2: Maybe, or maybe like windows in the ceiling.

P4: Yeah…

P2: I think that's more efficient

P1: Then you get like a lot of natural sunlight in the house

P3: Could it be then one floor better than Multiple floors or ..?

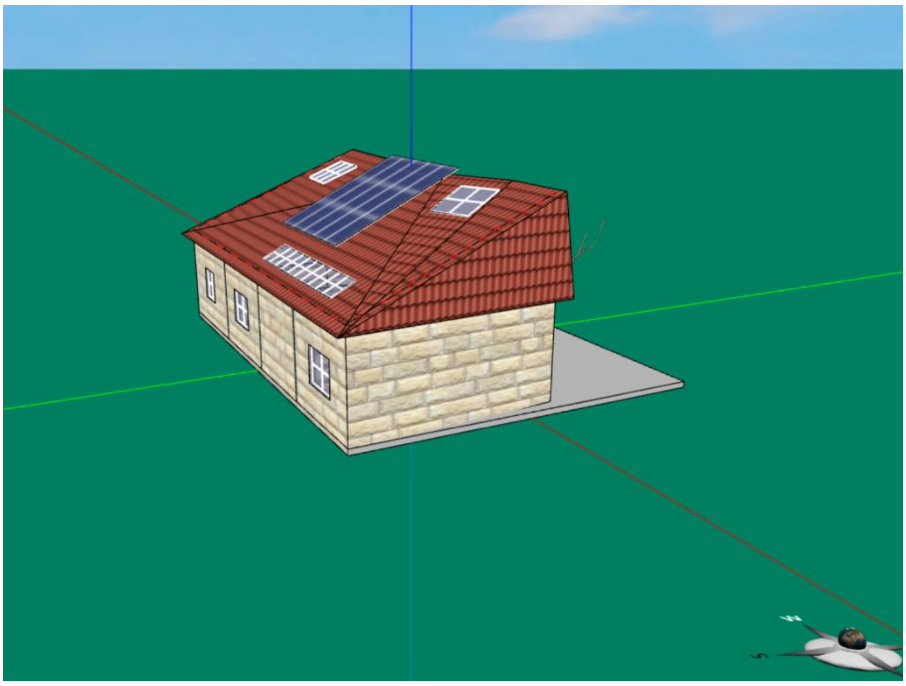
P2: Yeah, cuz then yeah. Yeah, it's like the lower floor won't get any sunlight from the top.

P3: So make a bit larger, but one floor.

P1: We have like a maximum width or square meters for the house, right?

P3: The only thing that he says here, the house platform must not exceed the default platform.

P1: Okay.



Excerpt 6:

P2: Okay, so what can you [do to] allow the maximum light into the house through the windows? Uhm…Roof windows, **how do you say that?**

P3: Uhm…Position windows on the roof, maybe one storey.

P2: Yeah, and also, okay, so one storey house and also...uhm…How do you say that? Sun rises in the east and sets in the west, **right?**

P4: Yeah

P2: To have more windows on those sides rather than north and south, I would say.

P1: Uhhum. Also for just the base design of the house, like if you're going to go for a nice roof and flair, it's going to eat up a lot of the budget. I feel like we should approach like the Cybertruck angle, where we minimize on like shapes and shit. A minimalistic yet somewhat nice as possible so we can invest more of the budget into solar panels…

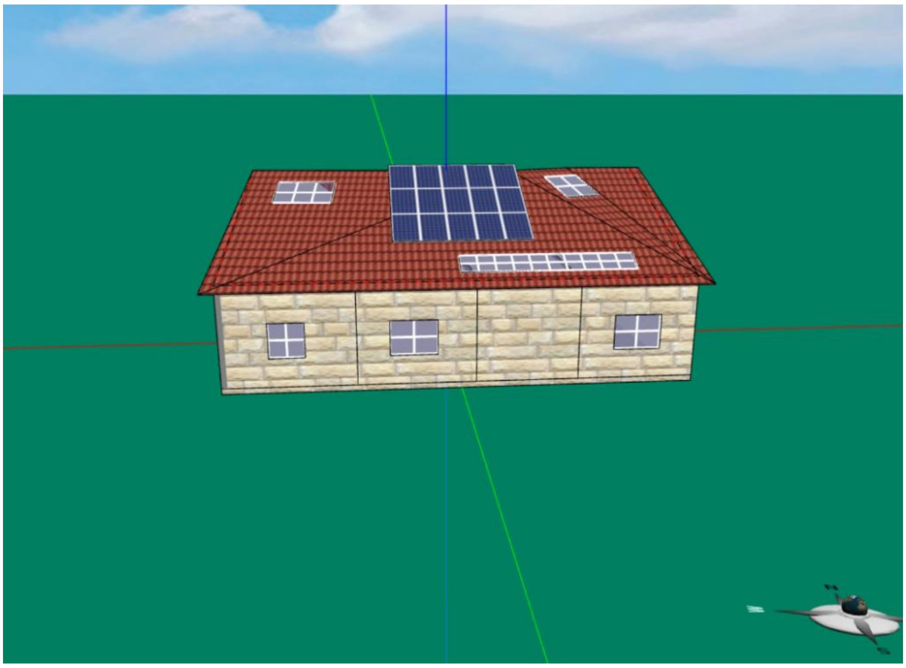
P2: Hmm yeah.

P1: …gardens, **I don't know**…

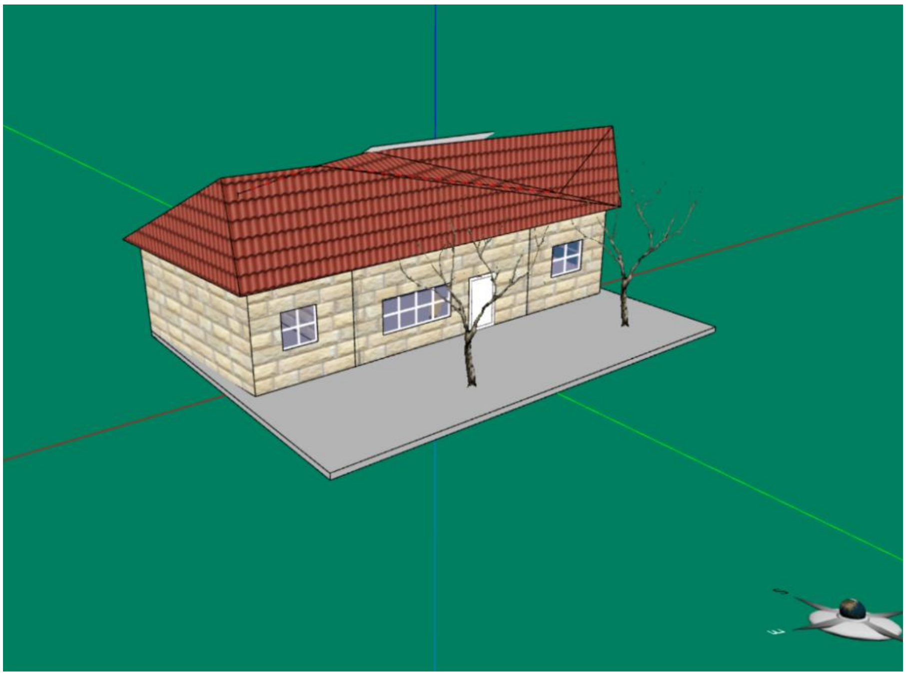
These conversation pieces (excerpt 6 and 7) also convey that the students debated the position of the windows and solar panels a couple of more times during the design period of the first house. They employed uncertainty reducing strategies by asking team members for information and confirmation when they felt unsure about an issue, in this case the position of the windows and solar panels. These issues were solved and appeared in the design by, once again, having an angled roof with the solar panels on it, windows on the roof and most windows positioned on the southern part of the house.

Excerpt 7:

> **P4:** Okay, so we wanted to slant it here. What's the north? Because we wanted to slant it to the...
>
> **P2:** East is that way, north. To the south, **right?** North is this side. This. This is north.
>
> **P3:** So we have south and north and we want it there, **right?** So, nice. We can... Yeah, exactly. Both way.
>
> **P4:** To the south.
>
> **P2:** But wait, what is the perfect... **Perfect position for solar panels?** South?
>
> **P4:** Yeah.
>
> **P2:** …that it's south-faced? Okay. So then we want it to have to be extended like this.



Next, there was a debate whether the group should plant trees around the house and what it could potentially do with the energy consumption during winter and summer. In this scenario, the reduction of uncertainty was chosen as a strategy by asking team members for confirmation about the presented information of trees giving shadows and cooling naturally the house, thus reducing energy costs. The resolution of the ambiguity resulted in having two trees in front of the house, on the northern side.



Excerpt 8:

P4: I think trees are good for keeping it cool during the summer.

P3: Uhhum…

P4: Not only the shadow on the house, but also the area around it. **I'm not sure** what it does during winter.

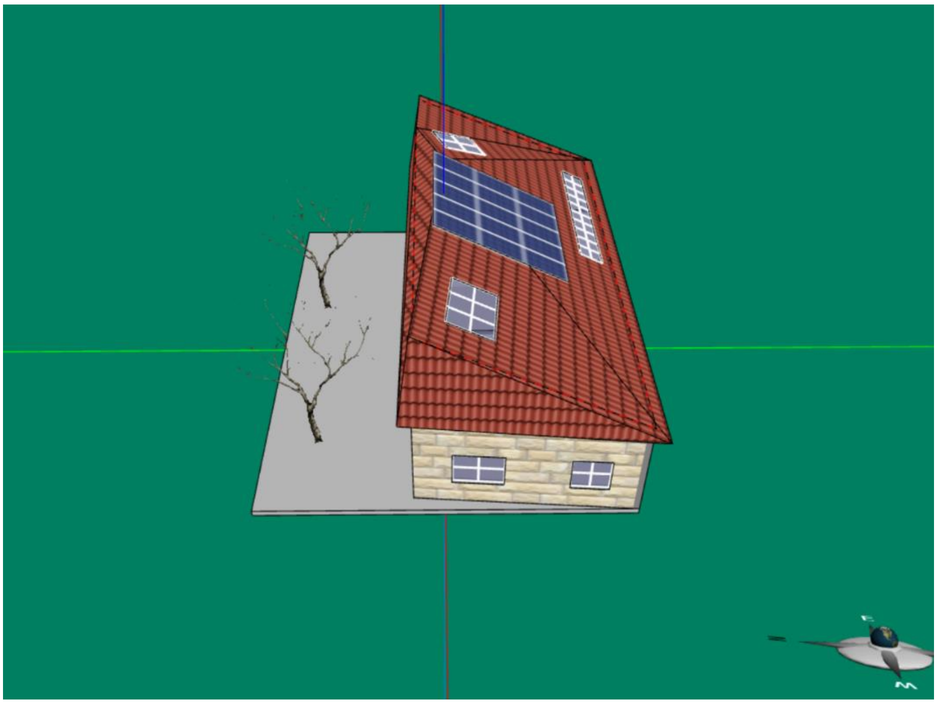
P2: Maybe it keeps the warmth in. It's like kind of an insulation layer around the house. Let's say you wear on the jacket. That's like kind of the thing around it.

P4: It's just… During winter, it's just leaves, so it doesn't create as much shadow.

P2: No, but you don't really need that in winter, **I think**.

P1: No, but that's good. That's good.

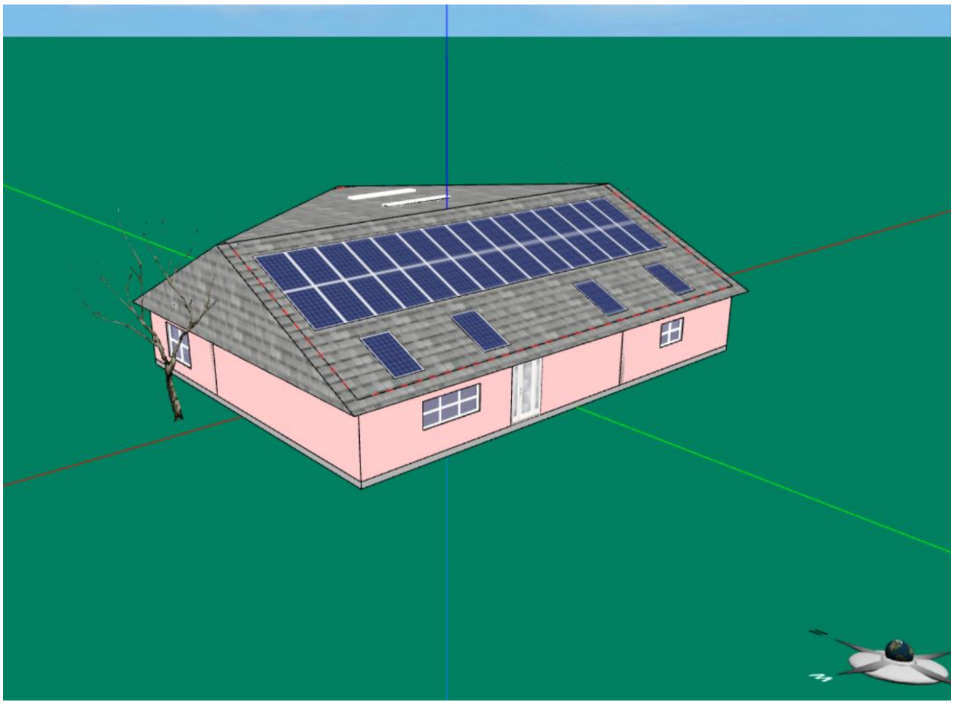
P4: Okay.



In the final design, student had to use the whole platform and had to redo everything based on the original house which could make it more energy efficient, in the budget and adherent to all task requirements. First, they had some confusion about the side where they should place the bedrooms and the solar panels. This debate was followed by a discussion about the main problem in Boston (where the design took place in the program) in which the participants were talking about hot versus cold as potential issues in order to decide how to place the windows and solar panels. This ambiguity was reduced by requesting information from team members. The design in the end included the front door, the living room, one room and tall the solar panels on the Southern side of the house, with an angled roof.

Excerpt 9:

> **P3:** Just for logic, sorry. **Where is the South where's North in this?** For the solar panel and windows.
>
> **P4:** I think we want this on the South. Yeah, or we want the bedrooms on the South.
>
> **P3:** We have solar panel windows also there. And if we make the same type of roof that we did before?



Next, the roof was up to debate. This conversation piece took place for a longer period of time. The team was busy with deciding how to create the roof exactly to make it the most energy and cost efficient. They employed reducing uncertainty as a strategy to deal with it. In the end, their design was influenced by this interaction in a way that the roof was a custom, angled roof.

Excerpt 10:

> **P1: Can we** make beams, like metal pipes or beams or **something?** Can we add that **somewhere?** Make a wire frame that makes it look like a roof, but then we fill in some parts with solar panels and we can just leave the costs.
>
> **P4:** The solar panels. Do they insulate enough to...

P1: No, but we don't. We don't care about that. We just make it flat, and then we make a roof out of wires.

P4: You do have houses that have roofs where solar panels are like built on the roof. Yeah. But then you don't have to work angle. You do need something underneath the solar panel. Yeah.

…

P4: Yeah, that's good. Okay, roof. Roof. Quick.

P3: Which one?

P4: This one, yeah. *points on the screen* And then custom.

P3: Custom?

P4: That works best. Yeah. And a cool bell. And you can move the points.

P1: I kind of like this. It's like a futuristic, symmetrical. Right now it's symmetrical.

P2: It is cool.

P4: Okay, wait. We can keep it symmetrical.

P4: Yeah, yeah. Or like, oh no. Wait. Maybe drag.

P2: Yeah, drag that to the middle. Or like, oh.

P1: Yeah, I like this.

P2: Can you put it a bit more to the middle? Yeah. To like the other, yeah, that one. To the other white dots. That one, yeah. Wow. Oh, nice.

The positioning of the windows were again causing ambiguity among the participants like in the previous design. They were reducing the ambiguity by trial-error in the program, placing windows on certain sides while thinking-aloud together. In the end, the Northern side got two smaller windows, the Southern a big and a small window and the two sides each got one-one window in the final design.

Excerpt 11:

P1: Windows?

P4: Just one…One window per room and then a big one for the living room. Nice. Right on the side. That's smart. I want to try to get the... OK.

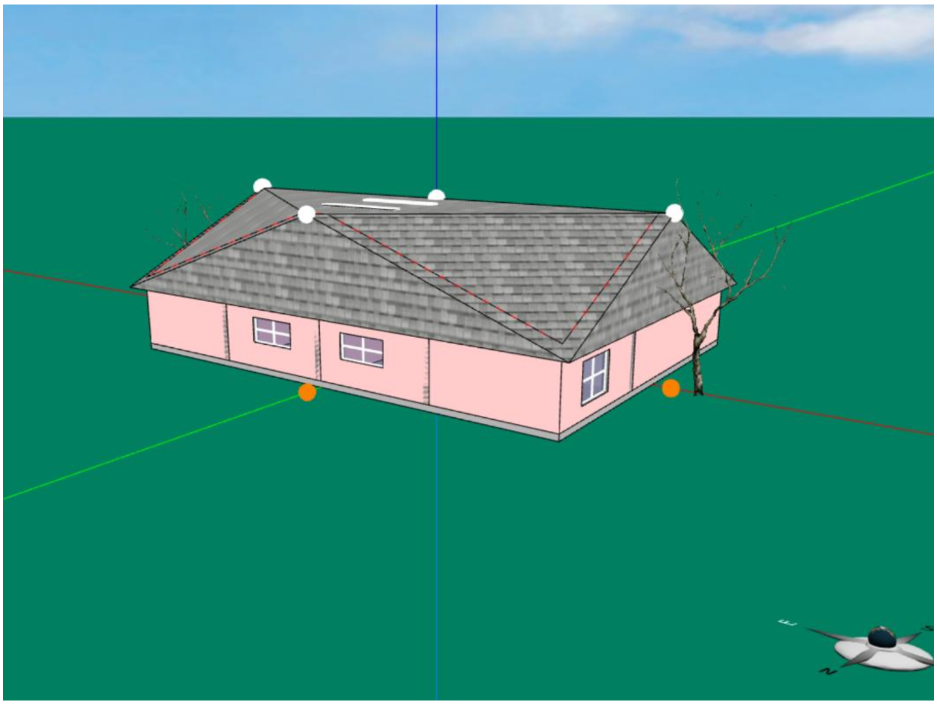
P2: You get a smaller window.

P1: I mean, it's only two meters high. I'm sure this is like, I was also probing. The ceiling would be like here. *pointing on the board*

P2: And then also the window maybe here. *pointing on the board*

P1: And then a window like this. *creating a window in the program*

P4: Yeah, that's good.



Next, building on previous experience, the students also incorporated two trees in the final design. The positioning of these regarding their use for energy consumption was causing uncertainty in the group. This was reduced by the participants continuously asking each other for information and confirmation with the placing of the trees.

Excerpt 12:

P4: Can you built two trees next to a window? The trees.

P1: Oh yeah, we want in front of the windows that we have no lights. **Can we have a few?**

P2: Can we put them like next to the house so that there is no blockage?

P4: The idea is that it blocks lights during the summer when it's too warm. OK, in winter…

P2: Yeah, OK, yeah, makes sense. Yeah, yeah.

P4: So. But yeah, **it shouldn't be too close** to the solar panel.

P3: Exactly.

P4: Maybe a bit to the left.

P3: Here? *making a tree in the program*

P2: Yeah.

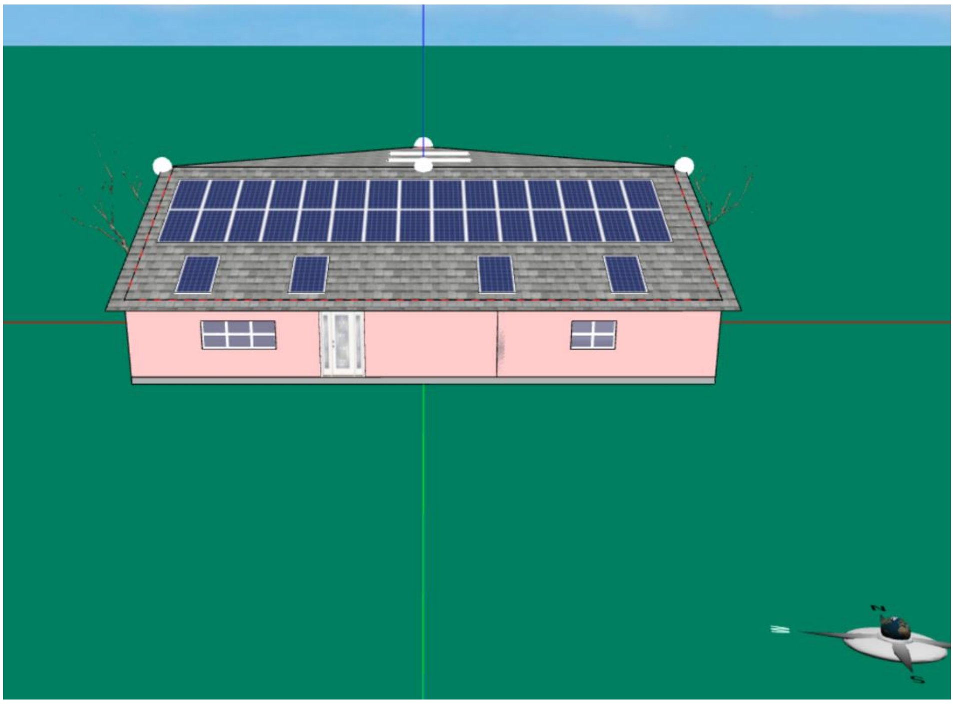
P3: Another one? **Maybe.** Here? Yeah. One here. Okay.

P1: And then maybe one here in the middle so it captures two roofs.

P4: Here with this sun north. There's some sun coming.

P2: Then at least I have a nice view.

P4: Yeah, it looks nice.



The last thing which created a discussion within the group was the colour of the house which appeared the following way:

Excerpt 13:

P3: The colour of the house?

P2: Yellow? Or pink?

P1: Pink. Yeah, pink is great. Pink is full. Let's make a Barbie house, yeah.

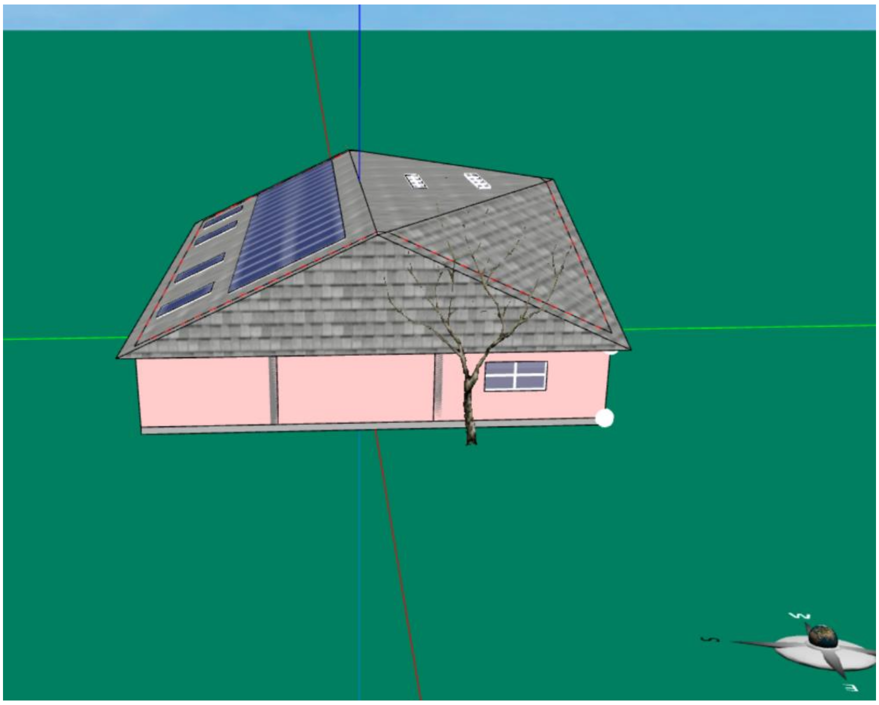
P2: Yeah. So this one can be... Pink, a little like light pink. Like light pink. Light pink?

P4: Let's make it look like a texture.

P1: It's the black and pink. Almost…

P3: Oh, that's so cute. OK

The uncertainty was reduced by trying to seek consensus within the group about the colour of the house. The final design became pink.



In the pictures below the two analyses of the group's initial and final house design can be seen (Figure 3 & 4).

Figure 3
The annual analysis of the first house design of student group 2

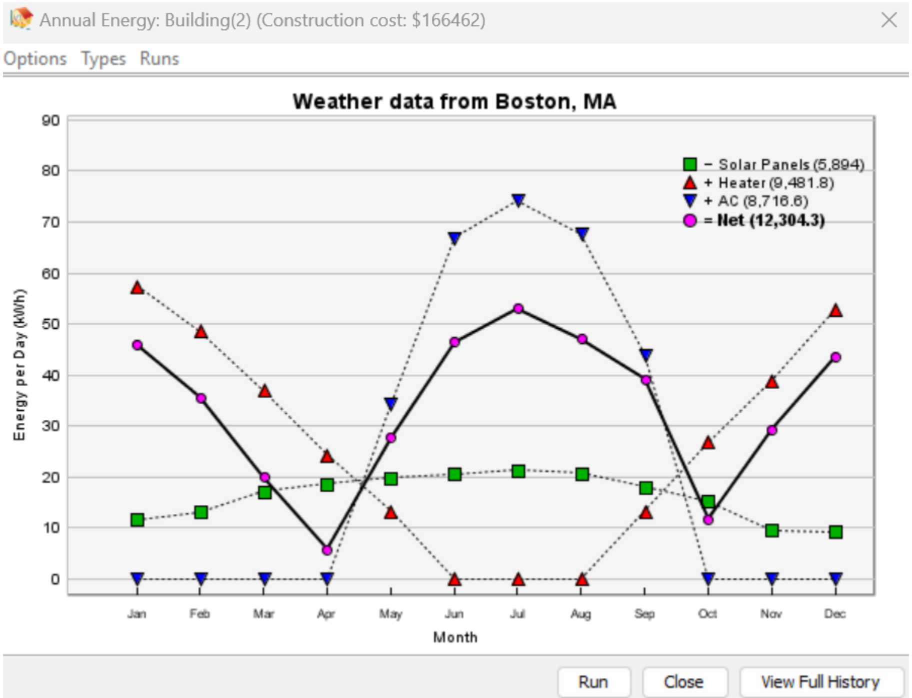
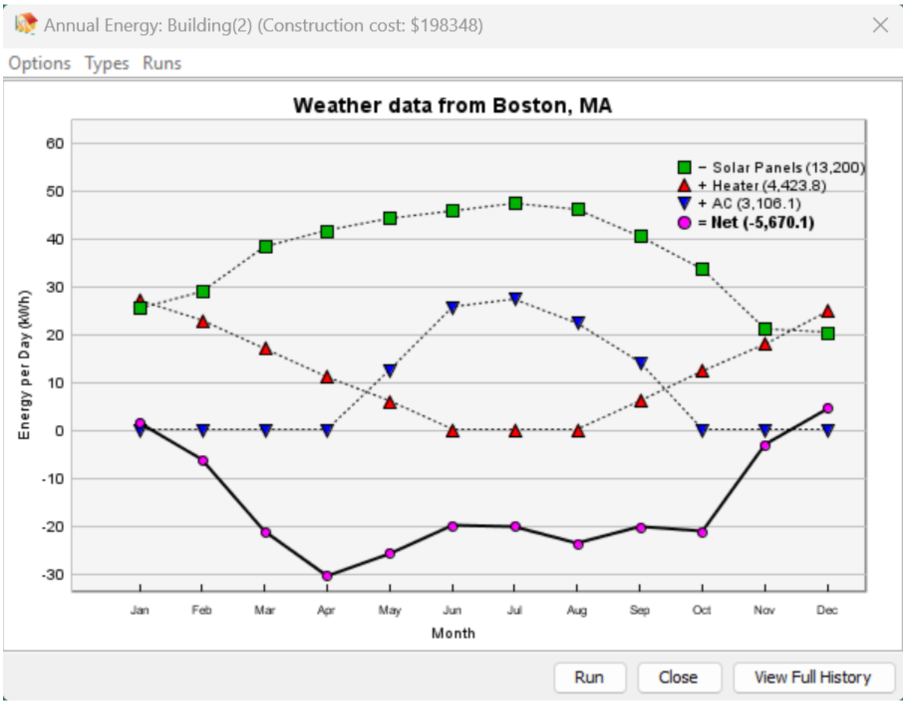


Figure 4
The annual analysis of the second house design of student group 2



These annual energy reports within the program show that although both houses were within the required budget, the first house has positive net energy throughout the year which indicates that it consumes more energy than it produces. On the contrary, the second house has a negative net energy for a significant part of the year which leads to the conclusion that it consumes less energy than it produces, especially in the summer months. These results could be due to the higher number of solar panels, better positioning, the positioning of the trees and overall design.

6 Discussion

The current qualitative study explored what kind of uncertainties university-level students experience while working on a computer-aided design enabled engineering project and what strategies they employed when facing these ambiguities. Lastly, it was discussed how the final design was influenced by the uncertainties and their management in the groups. The results were gained and interpreted from the observed interactions of students while working on the projects and the post-task interviews conducted with the students. While participants worked on collaborative problem solving, they experienced uncertainty regarding the design optimization of the task and issues regarding the scientific knowledgebase required to finish the task successfully. The efforts of the participants to manage the present uncertainty varied, sometimes it was a direct attempt to resolve it, sometimes the solution required the implementation of another strategy in the group.

Current study found that regardless the source of the uncertainty within the group, participants mostly employed strategies in order to reduce it. To be more precise, students chose to interact and ask for information from peers to resolve their ambiguity the most often. Moreover, there were some nuanced patterns of uncertainty management observed which need a deeper explanation. While most groups employed reduction strategy to deal with the ambiguity, some of them did it upfront and throughput the design process, others transitioned to or from increasing and maintaining uncertainty. As a matter of fact, groups 2 and 3 demonstrated a dynamic approach where they initially focused on reducing uncertainty before transitioning to strategies which increased or ignored ambiguity to return finally to reducing it, to close the circle. Group 3, in particular, maintained the level of uncertainty in a way that suggests a strategic approach of dealing with it. On the contrary, group 1 predominantly engaged in reducing the ambiguity intermittently, then briefly explored strategies to increase or ignore it before going back to reducing it. These patterns of behaviour within the groups suggest distinctive group dynamics and problem-solving approaches in each student sets.

The oscillation between group 2's constant change of reducing and increasing uncertainty and group 3's intermittent maintenance of it raises intriguing considerations regarding the role of uncertainty management strategies in collaborative engineering design tasks. The various transitions between strategies of the groups reflect a sophisticated engagement with creative problem-solving ways which help students navigate complexities and foster innovative problem solutions (Xu et al., 2023).

The student sets that oscillate between strategies of managing ambiguity might adapt quicker to newer information or challenges, but potentially could face more problems in group cohesion and focus. However, the distinct pattern of frequent shifts between reducing and increasing of uncertainty with a less emphasis on maintaining it is the strategy use of group 2, which suggests unique approaches to explore new ways of problem solving. This is an essential balance in engineering design task solutions where new ideas and efficiency are of a high value.

Additionally, it is suggested that those groups who started with reducing the uncertainty might create a stable foundation for a safe innovative behaviour instead of employing risk-taking behaviours. This is especially true for group 1 where members strongly focused on reducing uncertainty followed by a brief experimentation period with other strategies. This indicated their preference for a predictable and clear problem-solving path which might come at the expense of potentially exploring other, more innovative solutions.

Since one of the core elements of engineering design projects is experimenting with the design in order to optimize the outcome, it is not surprising that mostly groups faced uncertainty related to the design optimization while working on the task (Crismond & Adams, 2012). As a matter of fact, facing such ambiguities during the design process could potentially be beneficial for the learning curve of the students since uncertainty provides opportunities for them to debate and experiment on different aspects of the task and thus construct knowledge based on these discussions (Kapur & Bielaczyc, 2012; Jordan & McDaniel, 2014). These debates can be seen multiple times throughout the design process, for example in excerpt 1; 2 and 3, as well. Although uncertainty or failure are still often considered in learning contexts as detrimental, research conducted by Kapur and Bielazyc (2012) convened that when this ambiguity is properly managed, it could be beneficial for learning. Similarly, when students experiment with design activities, especially when they are not familiar with the nature of the task, it is expected to see them struggle with the lack of scientific knowledge. This was the case in the current study as well, since most participants were not familiar with the scientific concepts necessary to understand in order to build a simulated net-zero energy house. This can be observed in multiple presented excerpts, including excerpts 5 and 8 where students debate among each other about information related to isolation and the way how the sun and shadows impact the layout of the house. Overall, the lack of this knowledge caused less ambiguity for the groups than issues related to the design optimization, but still showed up at multiple occasions in the transcripts. What is important for students, as they face ambiguities of any kind, is knowing how to manage them effectively to turn them into learning opportunities.

Finally, when it comes to the last aspect of the study, one student group was highlighted to see how the types of uncertainties they faced and what strategies they employed to manage these ambiguities influenced their final design. This group faced almost equally as many design optimization issues as scientific knowledge-related ones. It is interesting to see that this group mostly employed strategies to reduce or increase uncertainty which lead them to complete the task successfully on the second try, but not the first.

In conclusion, in case of CAD-enabled engineering design tasks such as the one described in this research tend to be full of uncertainty, as one issue is solved by the group, another new ambiguity might emerge which needs to be managed. Hence, for students to achieve their learning goals in a project like this, they need to be capable of managing their experienced uncertainties.

7 Implications for practice

In this research, similarly to of Jordan & McDaniel (2014), as students work together on an engineering design task collaboratively, they employ coping strategies for maintaining, increasing, reducing, or ignoring uncertainty. The findings of the current study are especially applicable for engineering design and science learning projects since these trajectories employ multiple sources of ambiguity. Both of these domains are categorized by open-ended, ill-structured problem solving and design processes which create uncertainty by nature (Crismond & Adams, 2012; Dym et al., 2005). Additionally, as both design engineering and science learning are viewed as collaborative endeavours, uncertainty can spring from relational challenges with peers when attempting to come up with a solution to a task.

Understanding and conceptualizing uncertainty and its management can aid instructional designers and teachers to shape tasks in a way which facilitates learning. Dealing with uncertainty is essential in collaborative problem solving and design tasks. This research showed that the way how students respond to ambiguity and the strategies they employ to help them deal with it could potentially impact their performance in CAD-enabled engineering tasks. Namely, actively engaging in uncertainty within the design group, new ideas might spark and when it is socially supported, it might lead to a productive solution to the task. It can also be concluded that employing a computer-aided design program can be a useful tool to help teachers in engineering education by providing students with the opportunity to experiment and explore new ideas while facing uncertainty which, in return, could lead to fostering learning.

This study did not come up with any interventions or developments which could help students learn managing their uncertainties, but it could act as a first step towards such an intervention in the future. There are already existing suggestions for possible interventions in previous research. Examples of these include the research made by Metz (2004) where learners are taught to recognize their uncertainty which was later on broadened by Jordan (2012) by teaching students how to acknowledge their uncertainties. Finally, Jarvela and Hadwin (2013) and Jordan and McDaniel (2014) suggested that social interactions and recognizing and regulating peers' uncertainties in a collaborative setting can also be learned. Thus, the current research contributes to these previous findings and together with those it brings educational designers one step closer to coming up with an overall model which can teach students constructively deal with uncertainty and foster learning.

8 Limitations and future research directions

Like most studies, the current one also offered useful insights into uncertainty management but is not without certain limitations which are going to be addressed in the following paragraphs. Understanding and reflecting upon these shortcomings is crucial to provide improvement points for future research. The current study was based on qualitative research in which only 13 participants were selected via convenience sampling which could significantly impact the study's statistical reliability, validity, and general power. Since the selection procedure for participants was through convenience sampling, it by its nature, does not ensure a fully representative sample of the broader population. This raises concerns and can introduce bias while limiting the generalizability of the findings (Faber & Fonseca, 2014). Additionally, the small sample size can further undermine the experiment's external and internal validity as it may not adequately capture the complexity and diversity within the population being studied. (Bhandari, 2023). This can also lead to the results being not robust enough and not replicable, affecting the study's reliability. Moreover, drawing conclusions or applying the findings of the experiment in a population-wide, broader context could be challenging because of the lack of a sufficient participant pool (Crouch & McKenzie, 2006). Hence, regarding future research, it is recommended to increase the sample size and to use other sampling methods than convenience sampling to strengthen the reliability and validity of the study. Furthermore, existing research also suggests that demographic differences, such as gender, age, or ethnicity can mitigate the way and how often individuals might manifest uncertainty and how peers interpret this. That is why it is suggested that future research also explores such differences regarding uncertainty management in collaborative engineering tasks.

The inconsistency in the volume and quality of the video and audio data collected among different groups significantly influenced the qualitative analysis's efficacy. In certain groups, missing segments of the sessions presented challenges in correlating observed behaviours with specific markers. The initial aim was to document participant emotions, paralinguistic markers and their expression of uncertainty by gestures as well, however, the absence of comprehensive video and audio data restricted the depth of understanding in these areas.

For future studies, enhancing the recording setup in all sessions is advisable. This can be achieved by segregating the groups and ensuring clear visibility of each participant on camera. Additionally, equipping each participant with individual microphones will improve audio recording quality, capturing their voices more precisely. By overcoming these technical issues, a more dependable dataset for qualitative analysis can be obtained, thus reinforcing the findings' validity and interpretability.

When the participants reflected on their experience working on the design project in the context of the post-task interviews, they mentioned that their lack of motivation to perform well in the task played a crucial role in handling their uncertainties and issues with the group or the task. One student mentioned the following:

> "*It was difficult to really get invested in such a project just because I know I'm not going to do anything with this in the future, and it's just such a short time. So for me, it was difficult to actually right now isn't the same as I would assess other group partners in like a longer scale project at the university. So it's difficult for me to assess a lot of these things.*"

Another student explained during the interview that there was no real attachment to the task from their side, which made it less challenging to work together as a group:

> *"Well, I feel like because we were not very much emotionally attached to this project because it's just an experiment. It's not like, like an actual thing for studies. We I mean, at least I wasn't very much attached to my ideas. So if someone else came up with a*

different idea in mind, which. Was also good. I, I didn't mind letting go of my own idea. At least that was for me, the case, but might be different when it's like a bigger project to which I am more attached. But in this one I was more open for other ideas. So that made it also easier to, to to change to a different view."

These statements from the students led to the conclusion that the students were not motivated enough to engage in more meaningful task-related conversations or debates which resulted in a less cognitively demanding task overall. Furthermore, the task requirements were overall considered easily achievable for the university-level participants which resulted in less uncertainty overall. Thus, future research is required to either create a more complicated task for the students to work on in the CAD-enabled program, or to repeat the experiment on a lower educational level to gain a better insight into the possibilities of managing uncertainty in engineering design tasks.

9 Conclusion

This thesis, titled "Managing Uncertainty in Student Design Groups While Using a Computer-Aided Design Environment," delves into the ways university students manage uncertainty during collaborative computer-aided engineering tasks. It aims to construct a model of uncertainty management strategies beneficial for instructional design, particularly in the realm of collaborative problem-solving within engineering education.

The study employs qualitative methods, including video recordings and interviews, to explore the experience of uncertainty among student design groups engaged in engineering projects using CAD tools. The research identifies various types of uncertainties faced by students, such as design optimization issues and lack of scientific knowledge, and documents the strategies employed to manage these uncertainties, including reducing, ignoring, maintaining, or increasing uncertainty as per the situation demands.

The findings highlight the prevalence of uncertainty in engineering design tasks and the critical role of collaborative learning in managing such uncertainties. It underscores the necessity for instructional designs that support learning through the management of uncertainties, fostering an environment where students are encouraged to engage with and learn from the uncertainties inherent in design tasks. The study also points out the potential for CAD tools to facilitate this learning process by enabling students to experiment and explore design options in a collaborative setting. Additionally, this paper also raises several open questions regarding the optimal ways to support students in managing uncertainties in collaborative learning environments. These, among others, include: How does the level of uncertainty experienced by students impact their collaborative problem-solving processes and outcomes?; What role does peer interaction play in the management of uncertainties, and how can it be optimized to improve learning outcomes?; What specific tools or digital platforms can effectively support students in navigating uncertainties during collaborative learning tasks? Future research may explore the impact of different instructional designs on students' ability to manage uncertainties and the potential for integrating specific tools or resources to facilitate this process.

In conclusion, the thesis contributes to the understanding of how uncertainty is managed within student design groups in a CAD environment. It suggests that effective management of uncertainty is crucial for the learning process in engineering design, offering insights that can inform the development of instructional strategies and tools to enhance learning outcomes in collaborative design projects. Further research is recommended to expand the findings and develop more comprehensive models and strategies for managing uncertainty in educational settings.

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Appendices

Appendix A – Informed consent

Name ______________________

Code ______________________

Information Sheet

The purpose of this research is to unravel the relationship between *self-efficacy**, *self-regulation*** and uncertainty management within collaborative learning environments.

During this experiment, you will create an energy-efficient house with a small group. More information about the assignment can be found in the assignment form.

There are no risks associated with this research and this research project has been reviewed and approved by the BMS Ethics Committee

If you would like to withdraw from the study at any point please contact one of the researchers on

this project (details mentioned below).

During the research no personal information will be collected. Audio and video recordings will be made but they will not be able to identify the person on the recording. The audio data will be transcribed into text before being analysed, any personal information will be anonymised during this process. All data will be retained until the end of the project. Safety will be ensured by anonymizing all the data and only the researchers mentioned in this list will have access to the data.

Researchers:

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**Self-efficacy refers to an individual's belief in his or her capacity to execute behaviours necessary to produce specific performance attainments.*

*** Self-regulation is the ability to control one's behavior, emotions, and thoughts in the pursuit of long-term goals.*

Name ______________________

Code ______________________

Consent Form for Uncertainty in maker spaces and how it influences self-efficacy in students

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [22/11/2023], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	◻	◻
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	◻	◻
I understand that taking part in the study involves answering 2 questionnaires, being video-recorded which will be destroyed at the end of the study), being audio-recorded (and that this audio will be transcribed as text)	◻	◻
	◻	◻
Use of the information in the study		
I understand that information I provide will be used for a bachelor's thesis project		
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	◻	◻
I agree that my information can be quoted in research outputs	◻	◻
I agree to be audio recorded	◻	◻
I agree to be video recorded	◻	◻

Name ______________________

Code ______________________

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting. □ □

______________________ ______________________ ________

Researcher name Signature Date

Study contact details for further information: [***Name, email address***]

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Contact Information for Questions about Your Rights as a Research Participant (

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Appendix B – The General Self-Efficacy Scale (GSE)

General Self-Efficacy Scale (GSE)

	Not at all true	Hardly true	Moderately true	Exactly true
1. I can always manage to solve difficult problems if I try hard enough	☐	☐	☐	☐
2. If someone opposes me, I can find the means and ways to get what I want.	☐	☐	☐	☐
3. It is easy for me to stick to my aims and accomplish my goals.	☐	☐	☐	☐
4. I am confident that I could deal efficiently with unexpected events.	☐	☐	☐	☐
5. Thanks to my resourcefulness, I know how to handle unforeseen situations.	☐	☐	☐	☐
6. I can solve most problems if I invest the necessary effort.	☐	☐	☐	☐
7. I can remain calm when facing difficulties because I can rely on my coping abilities.	☐	☐	☐	☐
8. When I am confronted with a problem, I can usually find several solutions.	☐	☐	☐	☐
9. If I am in trouble, I can usually think of a solution	☐	☐	☐	☐
10. I can usually handle whatever comes my way.	☐	☐	☐	☐

Appendix C - AIRE, Self-Regulation scale

APPENDIX A

Section 1
WHAT WAS IMPORTANT TO YOU IN REGARD TO THE GROUP EXERCISE?

1.1. What was your major **goal** regarding this group exercise? ______________________

____

1.2. Apart from task completion, what **other things** have been important to you in this group exercise?

	not very important for me 1	2	3	a top priority for me 4
A. Get the highest possible mark, ideally a High Distinction	☐	☐	☐	☐
B. Make sure my grade is not going to be low because of the group	☐	☐	☐	☐
C. Learn as much as possible from others	☐	☐	☐	☐
D. Get new ideas from the group	☐	☐	☐	☐
E. Avoid being stressed	☐	☐	☐	☐
F. Not let the group down	☐	☐	☐	☐
G. Avoid looking incompetent	☐	☐	☐	☐
H. Have a good time, enjoy the experience	☐	☐	☐	☐
I. Make new friends, socialise with other students	☐	☐	☐	☐
J. Take personal responsibility for the work	☐	☐	☐	☐
K. Make sure I did not do more than others	☐	☐	☐	☐
L. Make sure everyone in the group contributed equally	☐	☐	☐	☐
M. Take the opportunity to practise my leadership skills	☐	☐	☐	☐

1.3. Which of the above have been the **most important to you** in this group exercise?

The most important First ☐ Second ☐

The least important ☐

Section 2
WHAT CHALLENGES DID YOU EXPERIENCE AS A GROUP ?

Below is a list of situations that you **may or may not have encountered** in your group and if so they would have **triggered strong feelings among (some) group members.** Please indicate for each of them, whether you experienced this in your group or not. If it happened, specify how big the challenge was, in your opinion.

Most of the situations below are described by a general statement followed by possible examples of how this might have happened. **The examples are not intended to describe the only way** the statements may be true. If the statement is true for you, and the example is not exactly how it happened in your group, please still rank the statement as you experienced it.

Please note that having to work through a challenge is not necessarily a negative experience. It may have turned into a positive experience and a successful outcome in the end.

It is assumed that each of these challenges would have triggered strong feelings among (some) group members

Our group experienced situation which triggered feelings where…

A. Our goals for the project were different.

For example - one/some people wanted to get a Distinction or High Distinction and others were just happy to get a Pass
- one/some people were so interested in the project that they were prepared to invest a huge amount of time but others were not interested.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

B. We had different priorities.

For example - Some people were more interested in socialising than getting on with the task.
- For some people, it was so important to have a pleasant atmosphere and friendly interactions that they were not prepared to question each other's views when discussing the task.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

C. We seemed to have incompatible styles of working.

For example - One/some people wanted to start working right away while others wanted to plan first and start to work after that.
- Others wanted to do other things first and work on the project later, saying that they always worked well under last minute pressure while others wanted to start as early as possible.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

D. We seemed to have different styles of interacting.

For example - one/some people were used to telling others (or others telling them) directly if they disagreed but others were uncomfortable with this and found this style of interaction confrontational
- one/some people were rather shy and others very outspoken
- two people were competing to be the group leader.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

E. People in our group did not connect very well with one another

For example - we had a different sense of humour
- we were not on the same wavelength
- our group found it very difficult to create a team atmosphere

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

F. One/some people were not fully committed to the group project.

For example - they did not make attendance at meetings their priority.
- they did not do their share of the work
- they seemed to expect that others would cover for them

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

G. People had very different standards of work.

For example - they said they could not find the information
- the quality of their work was unacceptable.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

H. Group members were not equal.

For example - Some tended to dominate, trying to impose their ideas, while others' didn't get a chance to contribute.
- Some people's opinions were not taken into account.

It did not happen	*It was a small challenge*			*It was a big challenge*
0	1	2	3	4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

I. Some people were easily distracted.

For example - they made and received phone calls on their mobiles during meetings
- they were interrupted by their friends
- they had other priorities at the time

It did not happen 0	*It was a small challenge* 1	2	3	*It was a big challenge* 4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

J. Our ideas about what we should do were not the same.

For example - One/some people had strong opinions of how we should proceed but others thought they were wrong.

It did not happen 0	*It was a small challenge* 1	2	3	*It was a big challenge* 4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

K. We differed in our understanding of the concepts/task.

For example - we were sometimes talking about different things even though we used the same words
- we had problems agreeing on what content to cover / ideas to include in our project
- our views were very different.

It did not happen 0	*It was a small challenge* 1	2	3	*It was a big challenge* 4
☐	☐	☐	☐	☐

Our group experienced situation which triggered feelings where…

L. We had different personal life circumstances or family / study & work commitments.
This made it very difficult

For example - to organise meetings
- for everybody to attend
- for people to stay long enough.
- to coordinate timetable

It did not happen 0	*It was a small challenge* 1	2	3	*It was a big challenge* 4
☐	☐	☐	☐	☐

Finally,

From the list above (A to L), please indicate below what you think were

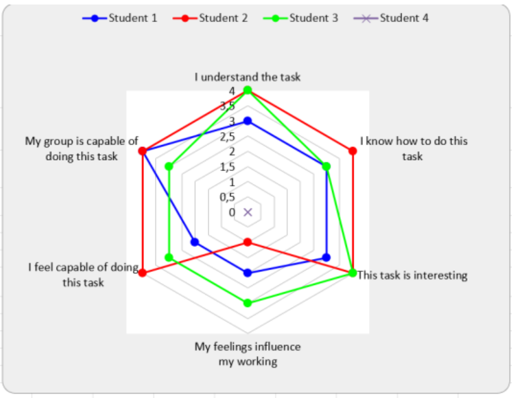
the two biggest challenges in your group (Insert letters): ☐ ☐

Appendix D – SSRL Charts

Combined RADAR Chart

	I understand the task	I know how to do this task	This task is interesting	My feelings influence my working	I feel capable of doing this task	My group is capable of doing this task
Student 1	3	3	3	2	2	4
Student 2	4	4	4	1	4	4
Student 3	4	3	4	3	3	3
Student 4	0	0	0	0	0	0

Likert Scales	
0	None
1	Low
2	Average
3	High
4	Very High

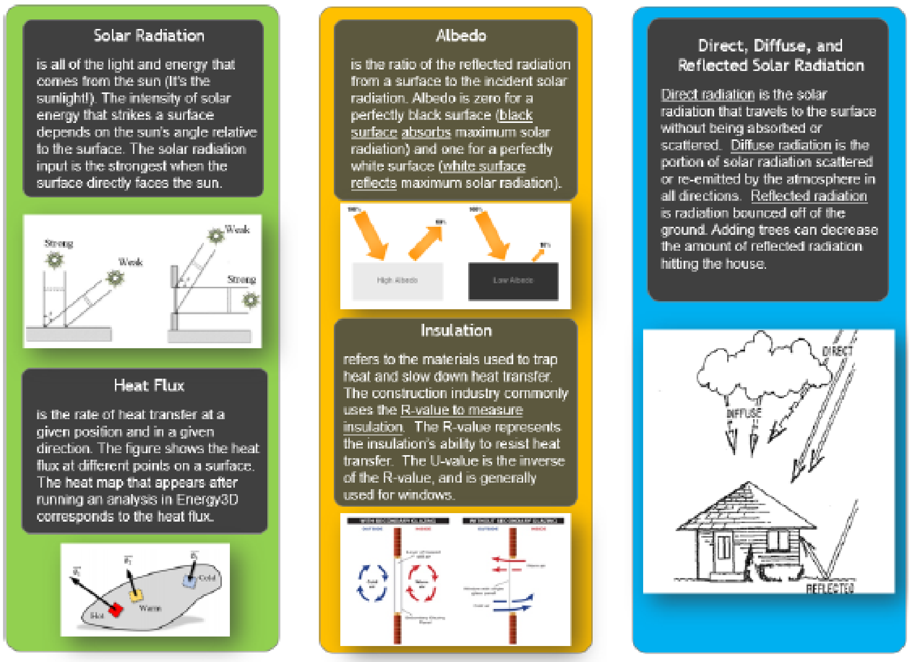


Appendix E – Uncertainty markers

Uncertainty Markers

Type of Uncertainty Marker	Description	Examples
Paralinguistic Markers		
rising prosody/intonation (Barr, 2003)		
Errors		
Disfluencies		
Hesitations, 5 types (Maclay & Osgood,1959)	unfilled pauses	silent pauses
	sounds of hesitation	"um", "er"
	filled pauses	"well"
	Repeats	
	false starts	
Hedges*		
Frequency	adverbs that refer to the probability of occurrence	often, seldom, never
Psychological	parenthetical adverbs that convey psychological uncertainty	expect, doubt
Ambiguous	modal verbs and auxiliaries that convey referentially ambiguous uncertainty	might, perhaps
Other Markers		
Questions: basic vs. wonderment (Berieter & Scardamalia, 1991)		"What do we do here?"
Approximators (Meaney, 2006)		"It's pretty long"
Statements of inability (Meaney, 2006)		"I don't know what to do"
Qualifiers (McFayden, 1996)		
Rephrasings (McFayden, 1996		
Self-reports of mental states that reflect metacognitive awareness (Anderson et al., 2001).		"I'm not sure" "I'm confused"

Appendix F – Information trifold



Solar Radiation

is all of the light and energy that comes from the sun (It's the sunlight!). The intensity of solar energy that strikes a surface depends on the sun's angle relative to the surface. The solar radiation input is the strongest when the surface directly faces the sun.

Heat Flux

is the rate of heat transfer at a given position and in a given direction. The figure shows the heat flux at different points on a surface. The heat map that appears after running an analysis in Energy3D corresponds to the heat flux.

Albedo

is the ratio of the reflected radiation from a surface to the incident solar radiation. Albedo is zero for a perfectly black surface (black surface absorbs maximum solar radiation) and one for a perfectly white surface (white surface reflects maximum solar radiation).

Insulation

refers to the materials used to trap heat and slow down heat transfer. The construction industry commonly uses the R-value to measure insulation. The R-value represents the insulation's ability to resist heat transfer. The U-value is the inverse of the R-value, and is generally used for windows.

Direct, Diffuse, and Reflected Solar Radiation

Direct radiation is the solar radiation that travels to the surface without being absorbed or scattered. Diffuse radiation is the portion of solar radiation scattered or re-emitted by the atmosphere in all directions. Reflected radiation is radiation bounced off of the ground. Adding trees can decrease the amount of reflected radiation hitting the house.

Heat Transfer

Can occur via three processes:

In the process of thermal conduction, thermal energy passes from molecule to molecule through direct contact.

In the process of thermal convection, thermal energy passes from one position to another through the flow of a fluid (liquid or gas).

In the process of thermal radiation, thermal energy is transferred by light. Trees around the building can help lower radiative and convective heat transfer.

Reference Guide for Building your Net Zero Home

1. Heat Transfer
2. Solar radiation
3. Heat flux
4. Albedo
5. Insulation
6. Direct, diffuse and reflected solar radiation