The learning experience of Heath: a parametric life cycle building performance assessment tool

The learning experience of Heath: a parametric life cycle building performance assessment tool

IOP Conf. Series: Earth and Environmental Science **1554** (2025) 012061 doi:10.1088/1755-1315/1554/1/012061

The learning experience of Heath: a parametric life cycle building performance assessment tool

T Säwén[1]*, I Mjörnell[1], A Sasic Kalagasidis[1] and A Hollberg[1]

[1]Department of Architecture and Civil Engineering, Chalmers University of Technology, Gothenburg, Sweden

E-mail: sawen@chalmers.se

Abstract. Although several tools exist for life cycle building performance assessment, they see little use in architectural design because aspects of practice integration have been neglected. In order to provide a practice-adapted analysis framework which can support important activities like sense-making and decision-making in early architectural design stages, when the information available is scarce and rapidly changing, we developed the life cycle building performance assessment tool Heath. Heath is integrated in the parametric design environment Rhino/Grasshopper, and combines existing, validated tools for quantitative assessment while providing a streamlined workflow which supports features like geometric modelling, goal setting, result interpretation, and alternative comparison. Heath was developed through iterative prototyping driven by the needs in a pedagogical environment, and tested by architecture students in a course emphasising sense-making with an environmental lens. The first prototype was implemented as a pure visual programming script, and the second prototype leveraged HumanUI to provide a panel-based interface. We found that in comparison to the initial, visual-programming based script, the panel-based, web-like interface improved the discoverability and liveness of the workflow, allowing students to focus on the interpretation of the environmental assessment insted of needing to spend a lot of time setting up the assessment model. The finding should guide software development for improved practice integration, and help improve educational approaches to introducing digital analysis tools in integrated architectural design education.

1 Introduction

The construction industry has a great impact on the environment as well as social wellbeing [1]. The integration of quantitative assessment methods, such as life cycle assessment and building performance analysis, in early architectural design stages has been shown to improve the final design outcome [2]. However, the multitude of tools available on the market see little use among architects because they have not been conformed to the specific and complex nature of architectural design [3], and the business context in which architects operate [4]. In this study, we emphasise the learning experience of students of architecture to identify how tools need to be adapted to allow users with limited technical expertise to still make sense of analysis results and use it to drive design forward with a life cycle building performance perspective [5]. The hypothesis explored is that by transitioning from a visual-programming based interface directly in Grasshopper, to a more user-friendly panel based version based in HumanUI, the tool learning experience will improve and allow the students to emphasise interpretating the results over challenges in terms of setting up the model and generating results. We thus trace the prototype development of the parametric life cycle building performance assessment tool Heath, which adds a HumanUI based interface to the performance analysis software suite Ladybug Tools [6] in the 3D modelling environment Rhino/Grasshopper.

The context of the study is a Master's level course in performance driven design, implementing an integrated design process where quantitative analysis results are utilised to ensure that the best-performing design alternatives are developed [7]. The course teaches topics of daylight, energy performance, and life cycle assessment in weekly workshops in the first segment of the course, followed by a second segment where the various analysis methods are combined in a multicriteria design optimisation process [8].

Several previous studies investigate tools based on the user experience and highlight factors important for ease-of-use by architects [5]. This includes ease of navigation and data entry [9], and the visual appearance of the interface [10]. These studies can be gathered under the umbrella term "architect-friendliness" [11]. While several key factors are identified in this body of work, none of the studies trace the utilisation of a tool in real practice, which would allow identifying factors which hamper and enable tool integration in actual use.

As a first step, we choose to investigate the pedagogical environment as it allows the systematic observation of tool adoption under consistent conditions, including instructions, type of design task, and user motivation, ensuring repeatability. Note that this situation can differ quite drastically from the one in real practice, where design requirements can shift rapidly [2], and the user time and motivation to learn new tools may be limited [3]. Nevertheless, we find architecture students to be an interesting user group, representing non-technical users within architecture firms. Hollberg et al. [8] found that even non-technical users like architectural students can implement assessment methods like life cycle assessment (LCA) if the tool user experience is good enough, and that the application of tools improve design outcomes. A survey carried out by J. Hopfe et al. [12] shows that there is no agreed-upon method of teaching the integration of quantitative analysis in design processes, and they highlight the importance of cross-disciplinary education combining architectural and engineering skills. Alsaadani and Bleil de Souza [13] highlight that there is a great difference between "consuming" analysis results from a black-box tool and "performing" analysis using a tools the mechanisms of which are well understood. Aish and Hanna [14] focus on learning in the visual programming paradigm in particular, by presenting cognitive dimensions which improve the understanding of parametric thinking. They highlight the need for more empirical work investigating students' learning experiences when adopting parametric tools. Lee et al. [15] provide an example of how the pedagogical environment can be used to understand the role of digital analysis tools in the design process, proposing that tools need to allow great conceptual freedom, support auto-completion from sketchy input, and provide support based on the user's skill level. In summary, teaching quantitative analysis to non-technical users in e.g. design education requires digital tools that provide conceptal freedom, auto-completion, and user skill-level-based support.

By focussing on the iterative, prototypal development of a life cycle building performance assessment tool, we aim in this study to deepen these perspectives by identifying how specific changes to the tool in terms of user experience affect the students' learning experience. By evaluating the performance of the students in relation to the learning goals defined in the course, we can directly compare two different tool implementations which offer different interfaces to the same analysis engine. Our findings are thus useful both for life cycle building performance assessment software developers focussing on the learning experience of the intended users, and for architectural educators who want to improve methods of teaching quantitative tool integration in design processes.

2 Method

We compare two prototypes for the life cycle building performance assessment tool Heath, as taught in a course in design integrated performance optimisation, and applied in student projects to improve daylight, energy performance, and life cycle impact of the designs. A timeline of the prototyping and data collection process is shown in Figure 1. Data is collected from digital pin-up sessions using a Miro board in the initial weeks of each course iteration. The graphical and textual material generated by the student groups during their design and analysis iterations was analysed in relation to the stated task performance and the learning goals of the course. This was then interpreted and linked to changes to the user experience implemented between the two course sessions.

2.1 Study context: Master's course

The study was carried out over two iterations (2024-2025) of the course ACE405 (Design and performance optimization in architecture) at Chalmers University of Technology, Gothenburg, Sweden. The course

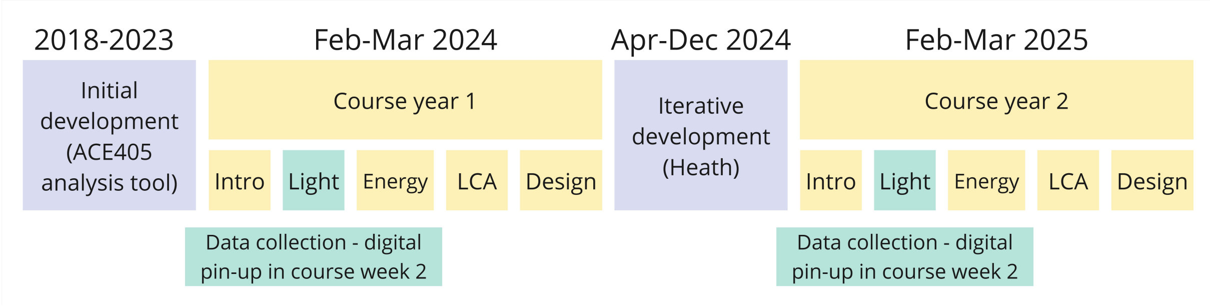

Figure 1: Timeline for tool prototyping and data collection in two course iteration.

is taken by fourth year architecture students. The students have mixed background and gender. 24 students attended the first course session, and 27 the second year. Each year, the students developed design projects divided into seven groups of three to five students.

At the beginning of the nine-week course, the students are introduced to the year's case study. Year 1, this was an office in a rooftop extension, and year 2, a preschool. The first five weeks, the students learn the application of the tool through workshops going through the various models. The workshops have the themes: sustainability assessment, daylight and environment, life cycle performance, energy performance, and multicriteria decision-making. These weeks start with an introductory lecture (3 hours) about the weekly topic, followed by individual research (3 hours), a software tutorial (3 hours), group work (6 hours) and the digital pin-up (3 hours). The final four weeks of the course, they utilise the tool to improve design proposal in a mimicked early stage design process. Inputs are provided by the teachers and externally invited architects through critique sessions and tutorials.

2.2 Data collection: learning experience

To be able to interpret the impact of user experience improvement on the students' learning experience and ability to achieve the learning goals, the digital pin-up sessions held during the first five weeks of each course session were used as a source of data. In these sessions, students prepare graphical and textual material representing their learnings using the tool during the week, and reflecting their current understanding of the design context. An example from one of the student groups in year 1 (week 2, daylight) is shown in Figure 2. We evaluate the performance of the students in relation to the tasks in the weekly assignment to the student groups, and to the overarching learning goals of the course. The stated learning goals, and an example of a task definition, are provided in Appendix A and B.

We developed a list of questions to more systematically evaluate the performance of students and to find a relationship with the user experience of the tool prototypes in different categories inspired by Säwén, Sasic Kalagasidis, and Hollberg [5]. The categories and related questions are shown in Table 1. Time efficiency, modelling freedom, and result interpretation were quantitatively investigated, whereas the assessment quality was graded 1-10 in relation to the learning goals for each group by the teaching team. It should be noted that no claims to statistical significance can be made considering the small sample size of seven groups each year, however, general trends can be observed and guide the evaluation and the future development of prototypes.

Table 1: Categories of aspects impacted by the tool learning experience, and questions guiding the evaluation of student performance

Category	Question
Time efficiency	How many graphical elements were taken into account?
Result interpretation	What tool outputs were used to support the students' arguments?
Assessment quality	To what extent did the students fulfill the learning goals?
Modelling freedom	What design parameters were selected for investigation?

IOP Conf. Series: Earth and Environmental Science **1554** (2025) 012061 doi:10.1088/1755-1315/1554/1/012061

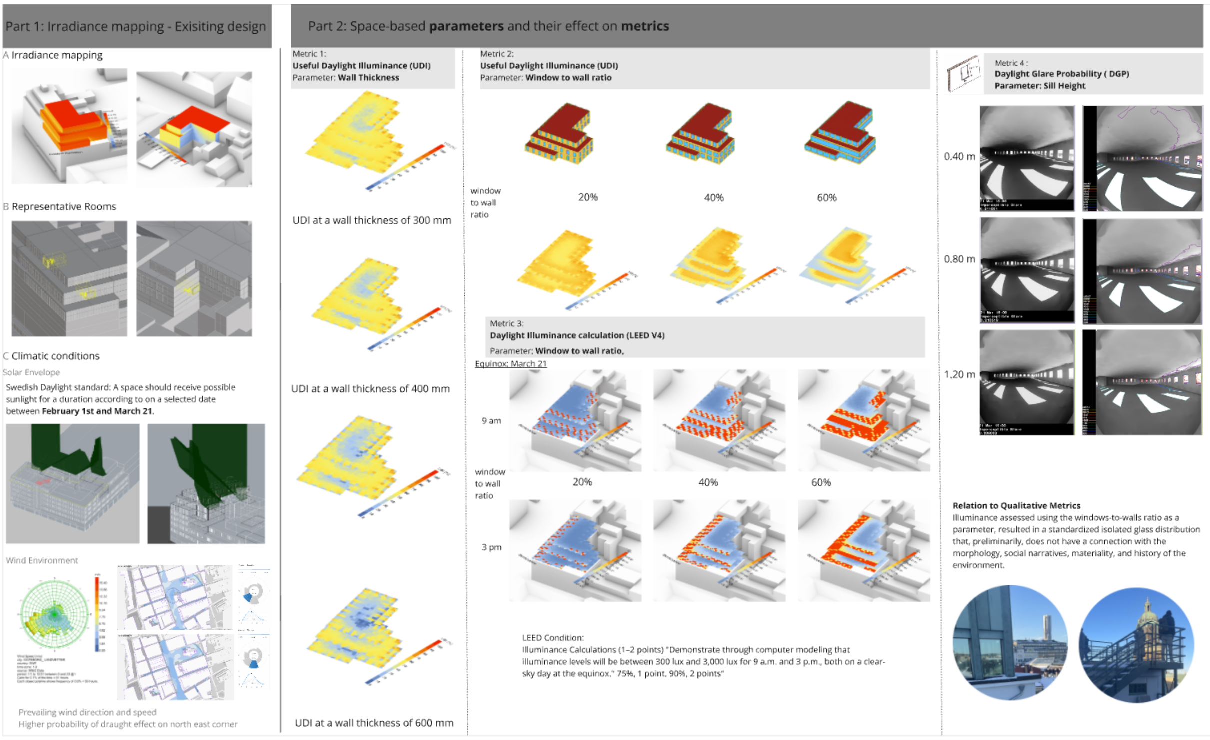

Figure 2: Example presentation prepared by a student group for the digital pin-up about daylight in the first course iteration.

3 Tool prototypes

We compare two iterations of the Heath life cycle building performance assessment tool in our study. The tool was developed within the context of the previously described course and its predecessor at Chalmers, and includes daylight, energy performance, life cycle assessment, and thermal comfort modules. The initial development has been described by Fantin Do Amaral Silva and Bergel Gómez [16], and the utilisation of early iterations is presented by Wäppling [17]. The tool prototypes share the same analysis engine foundation, using Ladybug Tools [6] as an interface in Rhino/Grasshopper for the EnergyPlus energy simulation engine, and the Radiance daylight simulation engine. Brimstone [18] is used to add embodied and operational emission factors to the Honeybee models created by Ladybug Tools.

The main difference between the initial prototype, which operates similarly to most available parametric analysis tools in Grasshopper, and the revised Heath prototype, is the addition of a streamlined interface, managing analysis models, allowing simple parameter inputs, and accessible visualisation of the analysis model and simulation outputs.

3.1 Tool prototype 1: ACE405 analysis tool

The initial prototype for the tool, referred to as ACE405 analysis tool, was used in year 1. It requires users to interact with the model and analysis directly in Grasshopper as shown in Figure 3. The tool, which is delivered as a Grasshopper definition, requires Rhino 7 and Ladybug Tools 1.6.0 to operate. The geometry modelling, and the various analysis modules, are grouped in the Grasshopper canvas for easier navigation. Standard Grasshopper workflows interacting with the Rhino model are implemented to manage geometry. The semantic data required to set-up the Honeybee model is managed by the user, also using standard Grasshopper workflows. Logic is hidden in clusters to a large extent to reduce the complexity for the operator. Analysis outputs are generated as data in the Grasshopper canvas, and in the Rhino viewport. Comparisons between model alternatives need to be carried out manually by the user. Five modules are available: Geometry import, Program and construction definition, Honeybee model

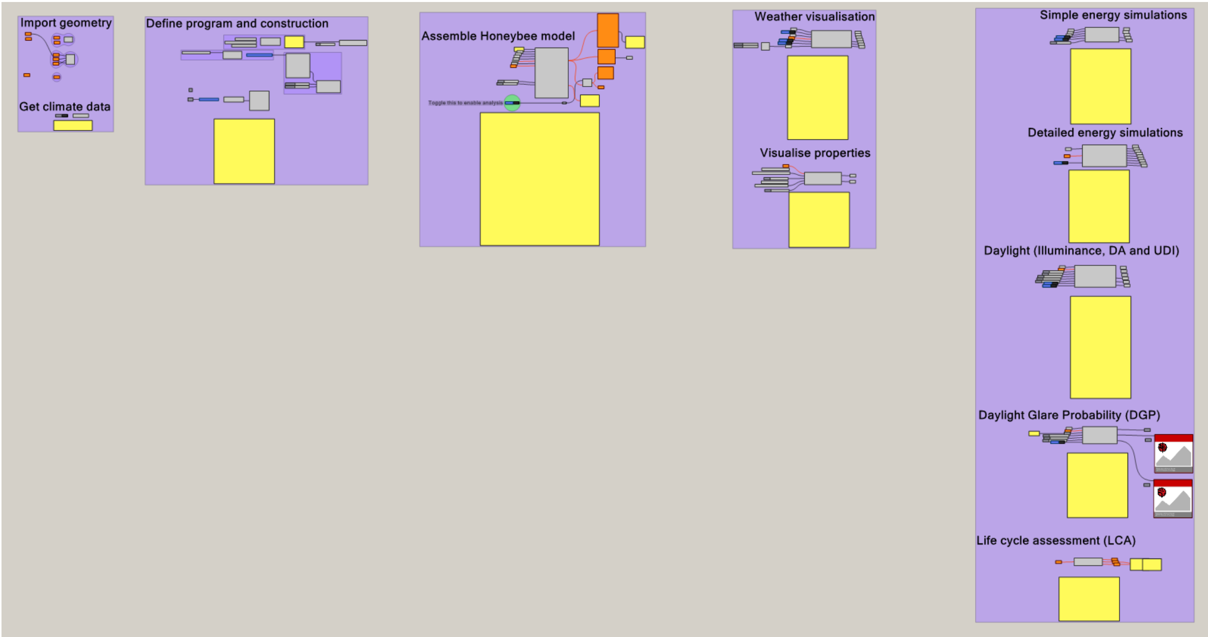

Figure 3: Overview of tool prototype 1 (ACE405 analysis tool) implemented in the Grasshopper interface

assembly, Model visualisation, Analysis (simple/advanced energy, daylight, glare, and LCA/embodied carbon). Documentation is provided using graphical elements in the Grasshopper interface. Error handling is limited to the built-in features of the Grasshopper components.

3.2 Tool prototype 2: Heath

The revised prototype for the tool, referred to as Heath (version 0.7.0), was used in year 2 [19]. The prototype adds a panel based interface as shown in Figure 4, removing the need to interact with the Grasshopper window. The tool is packaged as a Grasshopper definition with associated Python scripts and UserObjects, and requires Rhino 8, Ladybug Tools 1.8.0, and HumanUI 0.8.1.3, among other Grasshopper plugins which are automatically installed upon launching the definition. Six modules are defined: Geometry, Program, Construction, Assembly, Visualisation, and Analysis (daylight, energy, and LCA). The user steps through the workflow to select geometry, set-up and assemble the model, and visualise and analyse it. Geometry is managed through the Rhino layer manager, and the semantic information is stored as document user text. This allows saving materials, constructions, and whole models, for later manipulation and comparison. Results are output both graphically in the Rhino window, numerically in the Heath interface. Comparisons between two or more models can also be made in the interface, rendered as pop-up windows with bar charts comparing key performance indicators. Documentation is provided through help buttons in the interface, helping explain the modelling steps and the output indicators. Some error handling, including geometry filtering, is included and shown to the users through error messages in the interface.

4 Results and analysis

Our results focus on comparing the student outputs in the second weekly pin-up of each course iteration. The results are summarised in Table 2 and Table 3, organised according to the categories presented in Table 1.

The overarching trend in the student outputs is that when using the panel-based UI, the students were able to investigate a greater number of parameters and their effect on a greater number of indicators. They were also able to provide more extensive textual interpretation of the analysis results, beyond just presenting the graphical materials.

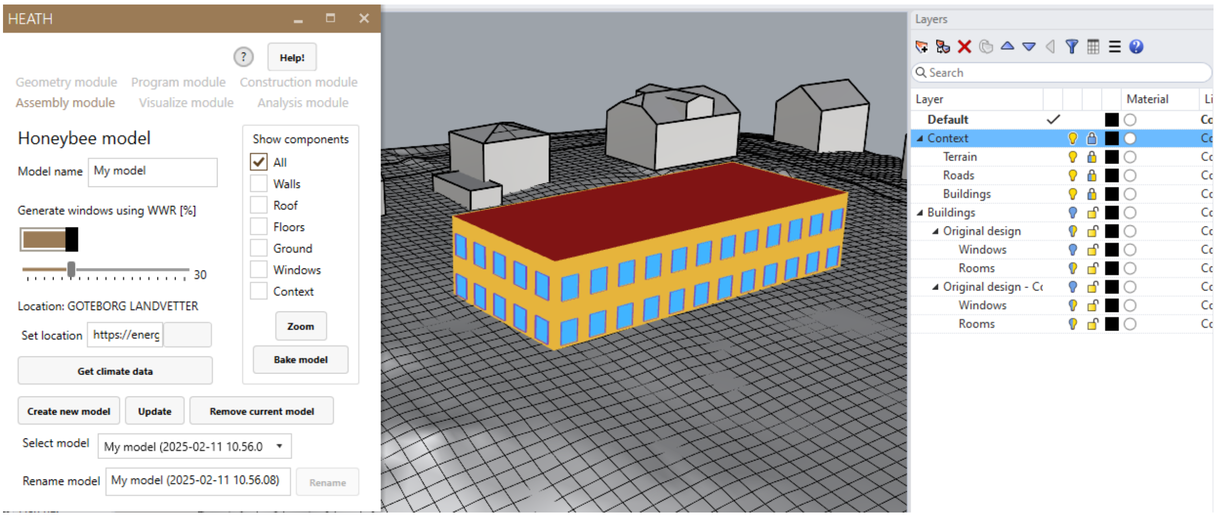

Figure 4: Example of the Assembly module of tool prototype 2 (Heath), overlayed with the Rhino viewport and layer manager visualising and managing the geometry.

Table 2: Results of the quantitative assessment. Numbers are averages for the seven groups each course session.

Category	Metric	Year 1	Year 2
Time efficiency	Average number of graphical elements	34	39
Result interpretation	Average number of utilised outputs	2.3	4.3
Assessment quality	Average teachers' assessment (1-10)	3.8	4.4

4.1 Time efficiency

A trend can be seen where more graphical material was utilised in year 2 compared to year 1. Assuming that a greater number of graphical elements included reflects the ability of students to produce more analysis outputs during the allotted time, this indicates that the ability to generate analysis outputs quickly for comparisons between more design options has been somewhat improved.

4.2 Result interpretation

A clear trend is that the average number of different types of analysis outputs utilised by each group increased from 2.3 on average year 1 to 4.3 on average year 2. The analysis modes include the following:

- Side by side 2D heatmap comparison
- Single value bar chart Spatial Daylight Autonomy (sDA)
- Illuminance
- Useful Daylight Illuminance (UDI)
- Daylight autonomy
- Direct sun hours
- Daylight Glare Probability (DGP)
- Wind rose

IOP Conf. Series: Earth and Environmental Science **1554** (2025) 012061 doi:10.1088/1755-1315/1554/1/012061

Table 3: Frequency of design parameters [20] being considered by the groups each year.

Design parameter	Category	Frequency year 1	Frequency year 2
Window frame depth	Shading geometry	2	0
External shading/louvers	Shading geometry	2	2
Window size	Window geometry	3	3
Window-to-wall ratio	Window geometry	2	3
Window shape	Window geometry	1	0
Skylights	Window geometry	0	1
Wall inclination	Building geometry	1	0
Building height	Building geometry	1	0
Building form	Building geometry	1	4
Building orientation	Building geometry	0	3

It should be noted that DGP was only analysed in year 1 as the analysis is more easily accessible there, whereas all groups utilised sDA bar charts in year 2 compared to none year 1 because of the capability of Heath to automatically generate this kind of output.

Two possible explanations can be mentioned for the change between years: either the panel-based interface simply makes changing between analysis modes and creating outputs for comparison easier, or the reduced complexity of interface improved the ability of users to autonomously find this functionality during their experimentations. This means, respectively, an improved discoverability and liveness as defined by Aish and Hanna [14].

4.3 Assessment quality

While the natural variability between course sessions can probably explain part of the change in the general assessment of the student projects, some general trends can still be observed. Whereas a majority of the groups in year 1 simply present the graphical outputs from the tool (5/7 groups), most groups in year 2 also provide textual explanation of the interpretation adjacent to the graphical outputs (5/7) groups. While this may be hard to directly explain through the changes to the tool, it could be presumed that greater attention to the interpretation of the results is only possible because generating the analysis outputs is more convenient, leaving more time for the interpretation step.

4.4 Modelling freedom

From Table 3, it can be seen that while the students year 1 were more focussed on shading and window geometry (10/13 parameters investigated) while keeping the building form intact, the year 2 students modified building form and orientation to a much greater extent (7/16 parameters investigated). While this may partly be explained by the different design tasks and contexts (rooftop office extension versus preschool in a previous park), another explanation could be that the ability to try different geometries was vastly streamlined in the second-year panel-based workflow, while retaining the ability to easily test window and shading options. The interpretation is that the ease of modifying a specific design parameter in the interface increases the likelihood of that parameter being investigated as part of the analysis.

5 Discussion

Whereas the limited sample sizes of our study prevent any statistical analysis of the quantitative results, some trends can clearly be seen. To further improve the understanding of the learning experience, additional methods like user surveys should be applied to compare the students' experiences during the different course editions. Wider tests of the tool versions with larger population would also improve the understanding of the results. A clear source of bias is the different case studies applied each year, which could affect the students' approaches as discussed above. Further, it cannot be ruled out that the lecture content supporting the students' learning changed slightly from year to year, influencing the metrics investigated in our study.

Nevertheless, our results can be said to support the findings in previous studies. We identified trends in terms improved learning outcomes linked to improved discoverability and liveness of the tool, as described by Aish and Hanna [14]. However, indications that other properties of parametric systems, like work-arounds and flexibility to adapt the analysis, were negatively affected when transitioning from the visual programming interface to the panel-based approach, need to be investigated in future work. We see also that the improved user experience could be linked to an improved understanding of the mechanisms of the analysis tool, allowing focus on interpretation rather than production of the analysis outputs. This helps transitioning the students from “consumers” to “performers” of analysis in the words of Alsaadani and Bleil de Souza [13].

6 Conclusion

We studied the integration of a life cycle building performance assessment tool in the architectural education context. We compared two prototypes for the parametric tool Heath as used in two course iterations by investigating the students’ outputs in digital pin-up sessions. We found that when transitioning from a visual programming based interface in Grasshopper to a panel-based workflow leveraging HumanUI, the students’ time efficiency, result interpretation, assessment quality, and modelling freedom, generally improved when comparing the two course iterations. This could be explained through spending less time setting up the model and generating analysis outputs, and more time interpreting results. This indicates that an improved user experience for tools used in pedagogical contexts can be linked to an improved learning experience. In future work, practice integration should also be tested in real-world projects, and further tool evaluation metrics like the ability to create work-arounds and adapt the analysis in detail should be added.

Acknowledgements

This research is funded by the Swedish Energy Agency, grant number 51715-1, and by Formas – a Swedish Research Council for Sustainable Development, project 2020-00934. We would like to thank Elena Malakhatka for supporting the study. We would also like to thank the anonymous course participants in ACE405 for contributing with their design projects, and more importantly, their curiosity.

Appendix A: learning goals

After completion of ACE405, students should be able to:

- *Knowledge and understanding*
  - demonstrate knowledge and understanding of the underlying methods for life cycle building performance assessment and multi-criteria design optimisation approaches
- *Competence and skills*
  - apply life cycle building performance simulation software in the early phases of the design process to answer specific design questions with a sustainability perspective
  - structure and document their multi-criteria optimisation process of the design solution
  - describe and evaluate design choices and their outcomes in terms of quantitative and qualitative criteria through several design iterations, using results from the simulation tools and simple architectural visualisations to support the argumentation
  - present their proposal in a series of digital and physical hand-ins
- *Judgement and approach*
  - describe, argue for, evaluate, and discuss their own and others proposals during a final critique together with university faculty and external reviewers

Appendix B: task description (week 2, daylight and environment)

1. Use irradiance mapping on the benchmark existing design.
   (a) Perform irradiance mapping and show in 3D isometric visualisation.
   (b) Based on the irradiance analysis, select representative rooms that represent locations in the existing design which have different lighting conditions.
   (c) (Optionally) investigate further climatic conditions, e.g. prevailing wind direction, or shading of adjacent buildings caused by the design.

2. Identify at least two design parameters which impact metrics tied to solar radiation (e.g. daylight and PV potential).
   (a) Diagrammatically present the parameter space and how the metrics are affected
   (b) Select at least three values for each design parameter, creating at least six design alternatives by changing the existing design, and evaluate them using the provided analysis script for one or two selected metrics.
   (c) Visualise the design alternatives in 2D or 3D to clearly show the differences.
   (d) Graphically present the results of the quantitative comparison between the designs.
   (e) Reflect on the performance of the design alternatives in relation to the qualitative metrics defined in Week 1.

References

1. Khoshnava SM, Rostami R, Mohamad Zin R, Štreimikienė D, Mardani A, and Ismail M. The Role of Green Building Materials in Reducing Environmental and Human Health Impacts. International Journal of Environmental Research and Public Health 2020; 17:2589. DOI: `10.3390/ijerph17072589`. Available from: `https://www.mdpi.com/1660-4601/17/7/2589` [Accessed on: 2023 Jun 15]
2. Meex E, Hollberg A, Knapen E, Hildebrand L, and Verbeeck G. Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design. Building and Environment 2018; 133:228–36. DOI: `10.1016/j.buildenv.2018.02.016`. Available from: `https://linkinghub.elsevier.com/retrieve/pii/S0360132318300829` [Accessed on: 2021 Jun 21]
3. Yu R, Gu N, and Ostwald MJ. Architects' Perceptions about Sustainable Design Practice and the Support Provided for This by Digital Tools: A Study in Australia. Sustainability 2022; 14:13849. DOI: `10.3390/su142113849`. Available from: `https://www.mdpi.com/2071-1050/14/21/13849` [Accessed on: 2023 Jun 15]
4. Gustafsson M. Design practice integration of a daylight analysis tool. MA thesis. Chalmers University of Technology, 2024. Available from: `https://odr.chalmers.se/items/dea9fce7-f872-457d-a1f6-909a7681bc62` [Accessed on: 2025 Mar 2]
5. Säwén T, Sasic Kalagasidis A, and Hollberg A. Critical perspectives on life cycle building performance assessment tool reviews. Renewable and Sustainable Energy Reviews 2024; 197:114407. DOI: `10.1016/j.rser.2024.114407`. Available from: `https://www.sciencedirect.com/science/article/pii/S1364032124001308` [Accessed on: 2024 Apr 17]
6. Sadeghipour Roudsari M and Pak M. Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. *Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association.* Chambéry, France, 2013 :3128–35
7. Negendahl K. Building performance simulation in the early design stage: An introduction to integrated dynamic models. Automation in Construction. 2015; 54:39–53. DOI: `10.1016/j.autcon.2015.03.002`. Available from: `https://www.sciencedirect.com/science/article/pii/S0926580515000369` [Accessed on: 2021 Aug 18]
8. Hollberg A, Ebert M, Schütz S, Cicek B, Gumpp R, and Ruth J. Application of a parametric LCA tool in students' design projects. *Proceedings of Sustainable Built Environment SBE16 Hamburg.* 2016
9. Nielsen AN, Jensen RL, Larsen TS, and Nissen SB. Early stage decision support for sustainable building renovation – A review. Building and Environment 2016; 103:165–81. DOI: `10.1016/j.buildenv.2016.04.009`. Available from: `https://www.sciencedirect.com/science/article/pii/S0360132316301238` [Accessed on: 2021 Sep 16]
10. Bazafkan E. Assessment of Usability and Usefulness of New Building Performance Simulation Tools in the Architectural Design Process. MA thesis. TU Wien, 2017

11. Weytjens L, Attia S, Verbeeck G, and De Herde A. The 'Architect-friendliness' Of Six Building Performance Simulation Tools: A Comparative Study. International Journal of Sustainable Building Technology and Urban Development 2011; 2:237–44. DOI: 10.5390/SUSB.2011.2.3.237. Available from: https://doi.org/10.5390/SUSB.2011.2.3.237 [Accessed on: 2022 Jan 24]
12. J. Hopfe C, Soebarto V, Crawley D, and Rawal R. Understanding the Differences of Integrating Building Performance Simulation in the Architectural Education System. *Proceedings of IBPSA-NVL Conference.* 2017. DOI: 10.26868/25222708.2017.319. Available from: https://publications.ibpsa.org/conference/paper/?id=bs2017_319 [Accessed on: 2025 Feb 11]
13. Alsaadani S and Bleil de Souza C. Performer, consumer or expert? A critical review of building performance simulation training paradigms for building design decision-making. Journal of Building Performance Simulation 2019; 12:289–307. DOI: 10.1080/19401493.2018.1447602. Available from: https://doi.org/10.1080/19401493.2018.1447602 [Accessed on: 2023 Dec 5]
14. Aish R and Hanna S. Comparative evaluation of parametric design systems for teaching design computation. Design Studies. Parametric Design Thinking 2017; 52:144–72. DOI: 10.1016/j.destud.2017.05.002. Available from: https://www.sciencedirect.com/science/article/pii/S0142694X17300327 [Accessed on: 2023 Jan 26]
15. Lee S, Choi B, Maia CC, Park J, Youm SH, and Lee S. Integrating simulation into design: an experiment in pedagogical environments. International Journal of Technology and Design Education 2022; 32:2257–77. DOI: 10.1007/s10798-021-09682-6. Available from: https://doi.org/10.1007/s10798-021-09682-6 [Accessed on: 2022 Oct 24]
16. Fantin Do Amaral Silva G and Bergel Gómez R. Energy performance modelling - Introducing the Building Early-stage Design Optimization Tool (BeDOT). MA thesis. Chalmers University of Technology, 2018. Available from: https://odr.chalmers.se/handle/20.500.12380/256091 [Accessed on: 2022 Mar 31]
17. Wäppling L. Multi-Objective Building Performance Simulation - Integrating Building Performance with Architectural Modelling in Early Stage Design. MA thesis. Chalmers University of Technology, 2019. Available from: https://odr.chalmers.se/handle/20.500.12380/300085 [Accessed on: 2021 Nov 18]
18. sawenchalmers. Brimstone. URL: https://github.com/sawenchalmers/brimstone. 2023. Available from: https://github.com/sawenchalmers/brimstone [Accessed on: 2025 Feb 11]
19. sawenchalmers. Heath. URL: https://github.com/sawenchalmers/heath. 2025. Available from: https://github.com/sawenchalmers/heath [Accessed on: 2025 Feb 28]
20. Wang X, Teigland R, and Hollberg A. Identifying influential architectural design variables for early-stage building sustainability optimization. Building and Environment 2024; 252:111295. DOI: 10.1016/j.buildenv.2024.111295. Available from: https://www.sciencedirect.com/science/article/pii/S0360132324001379 [Accessed on: 2024 Feb 20]