Using Heliodon for Solar Building Design Education in the Age of Computer Simulations

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Abstract

Nowadays, engineering students tend to focus on computer simulations for the study of real-world phenomena, although in many cases they do not understand the basic principles behind the specific software. Therefore, in the time of computers, using a heliodon (physical device for solar analysis) for educational purposes might be an encouragement. The presented paper discusses the differences between analogue (heliodon) and digital (computer simulation) methods for determining insolation through educational work with students at bachelor level. Through the comparison of insolation results obtained by computer software and those obtained by heliodon, the potential accuracy error of the heliodon was evaluated. The results showed that the highest achieved accuracy of the analysed heliodon was at scale 1:400 (average error 7% on the equinox and 20% on the winter solstice). Furthermore, a questionnaire was handed to the students during the Bioclimatic design course at the University of Ljubljana. The students evaluated the user-friendliness of heliodon as sufficient (mean SUS score was 83.3).

Keywords: solar geometry, insolation, teaching tools, System Usability Scale (SUS), heliodon

1. Introduction

The knowledge about (energy) performance of buildings is becoming an increasingly important subject for architects, architectural, civil and environmental engineers. Consequently, the curricula of architecture and engineering schools are giving the field ever greater attention resulting in introduction of new courses as well as whole study programs dedicated to the field of architectural engineering (DTU, 2018; KTH, 2018; TU Berlin, 2018; UL, 2018; UMONS, 2018; University of Leeds, 2018). Due to the complexity of the subject, characterized by the need for holistic treatment of buildings (e.g. energy performance, passive design, daylighting, renewable energy integration, indoor comfort, environmental impacts, etc.), sophisticated and complex simulation tools are often used during the educational process. Such approach assists students to address the problems at hand with great detail and complexity. However, from the educational point of view, the sole reliance on complex simulation tools such as EnergyPlus can obscure the basic principles governing the performance of buildings, resulting in poor understanding by students. It can be argued that for the purpose of education of engineers the understanding of basic principles is crucial, as it establishes solid foundations on which advanced knowledge can be built. In the context of energy performance of buildings and daylighting, one of such basic principles is understanding of solar geometry and its impacts (e.g. solar gains, shading, etc.) on the design of building elements and components.

The teacher is faced with the dilemma of how to present the subject of solar geometry to the students enrolled into engineering courses. The two most common approaches are the use of sun charts or diagrams (either in physical or digital form) and the use of computer models (Muneer et al., 2004; Prinsloo and Dobson, 2015). However, both methods lack in plastic representation of the problem, as they are disassociated from the real world phenomena and, therefore, demand an abstract and conceptualized understanding from the students. This in particular was identified as a problem through our educational work with students in junior years of Civil Engineering and Sanitary Engineering (i.e. Public and Environmental Health Professionals) at the University of Ljubljana (UL), Faculty of Civil and Geodetic Engineering (UL FGG) and Faculty of Health Sciences (UL ZF), respectively. Through practical work with the students, we recognised that some students have problems with the interpretation and relation between the abstract results gained from sun charts and/or computer simulations and the real world case of the studied building. As an alternative, a more intuitive approach using solar emulators can be implemented, where students use physical models of buildings under an artificial sky or a heliodon device (Lechner, 2018, 2015; Shaviv, 1999) to perform solar analysis. The main benefit of such approach is that the relation between building shading and the apparent position of the sun in the sky is more evident in spatial as well

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as in temporal context. This also provides a more plastic representation of the studied problem as well as a gradual translation between the real world phenomena and the abstract engineering tools used for its representation. However, the use of heliodon and especially artificial sky can present its own set of problems, mainly connected to the physical size, cost of construction and maintenance of such devices as well as to the accuracy of results.

This paper presents a heliodon emulator constructed at UL FGG (Fig. 1). Further on, its accuracy was tested and compared to computer simulation. Because the primary function of the UL FGG heliodon is to be used in the context of educational process, the feedback from students regarding the use of the device was acquired through a simple survey conducted within the course Bioclimatic design run at both faculties (i.e. UL FGG and UL ZF). Finally, the pros and cons of using heliodon as a teaching instrument in the digital age, when engineers are predominantly dependent of the use of computer simulations, is debated.

Fig. 1: Heliodon used for the educational purposes within the Bioclimatic design course held at UL FGG and UL ZF.

2. About heliodon

Broadly speaking, heliodon is any device that enables to physically (i.e. using models) simulate the effects of yearly and daily movement of the Earth around the Sun. All such devices, irrespective of theirs construction and design, represent the Sun-Earth geometric relationship through a lococentric view (Szokolay, 2014, 2007), where it is assumed that the observed location is fixed and the Sun moves around it. Because of this assumption, they are in fact emulators and not simulators, because they represent the effect of the Sun-Earth geometric relationship and not the physical process behind it. The main objective of heliodons in architectural applications is to determine the insolation of building surfaces (e.g. walls, windows, roofs, etc.), which has a direct impact on the energy performance as well as daylighting of buildings. All heliodon devices can be classified into one of the two categories (Cheung et al., 2012):

- Heliodons with fixed or movable light source representing the Sun and a movable and/or rotatable surface representing the Earth surface onto which the model of a building is placed. The tilting of the surface with the model defines the geographical location (i.e. latitude), the movement of the light source defines the change in seasons (i.e. months) (Cheung et al., 2012; Lechner, 2015), while the rotation of the model defines the hours in a day. Such devices are compact and easy to use. However, they are conceptually unclear, as the apparent movement of the Sun across the sky, observable in reality, is not presented (Lechner, 2015).
- The second group is comprised of heliodons with fixed horizontal surface representing the surface of the Earth and the location of the model (Figs. 1 and 2). The light source representing the Sun is rotated around the analysed fixed model using a ring representing the Sun trajectory in a specific month (Cheung et al., 2012; Doberneck and Knechtel, 2013; Lechner, 2018, 2015; Olgyay and Olgyay, 1957). The rotation of the ring with

the light source emulates the daily movement of the Sun (i.e. hours), while the tilting of the ring with respect to the observed surface defines the geographical location of the analysed model. Individual rings represent monthly Sun trajectories. Such devices are conceptually clear, because they faithfully (although transformed) represent the observable Sun-Earth relationship perceived from the surface of the Earth. A drawback of this type of heliodons is their size, as they need to be large in order to facilitate the analysis of larger models; their accuracy is strongly related to the distance between the light source and the observed model (Lechner, 2015).

Because the presented UL FGG heliodon prime intention was to use it in the educational process, the type with fixed horizontal surface was chosen, because it is conceptually clear and therefore easier to understand by the students. The basic scheme of the UL FGG heliodon was taken from the heliodons presented by Lechner (Lechner, 2018, 2015) and by Doberneck and Knechtel (Doberneck and Knechtel, 2013) and adapted to suit the needs of the educational process and physical limitations of the classrooms. Therefore, the main limitation in the design of the heliodon was its final physical size, which was limited by the 900 mm wide and 2300 mm high door of classrooms at the UL FGG building. As a result, all other dimensions were derived from this limitation, thus also defining the maximum sizes or scales of models that can be tested with sufficient accuracy. The UL FGG heliodon consists of a horizontal surface placed in the centre of the heliodon with a diameter of 400 mm, onto which a model of building can be placed. Surrounding it, there are the three rings with light sources depicting the Sun trajectories at equinoxes as well as summer and winter solstices (Fig. 2), effectively defining the extremes of the apparent Sun movement across the sky. These rings can be rotated in order to move the light source to the correct hour of a day (i.e. 15° rotation = 1 h). They are also fixed into a fourth larger ring that can be rotated around the longitudinal axis of the heliodon (Fig. 2). Tilting the external main ring defines the geographical location of the analysed model by setting the latitude from 0° (i.e. equator – rings are vertical) to 90° (i.e. pole – rings are horizontal). The rotation of the inner ring as well as of the tilting of the main ring are manual. The light sources used to depict the Sun are remotely controlled battery powered LED lights with maximum luminosity of 900 lm.

The main limitation influencing the accuracy of the UL FGG heliodon is the use of non-parallel light source, meaning that the LED lights will also cast non-parallel shadows, which is not the case with the real Sun. This limitation could be addressed by placing the lights farther away from the centre of the heliodon. However, this would increase its size, which was limited by the above mentioned width of the classroom doors. Alternatively, a quasi-parallel light source using Fresnel lenses could be used (Cheung et al., 2012). Nevertheless, we opted not to implement such a design due to its bulkiness and complexity and rather opted for simplicity while sacrificing some accuracy.

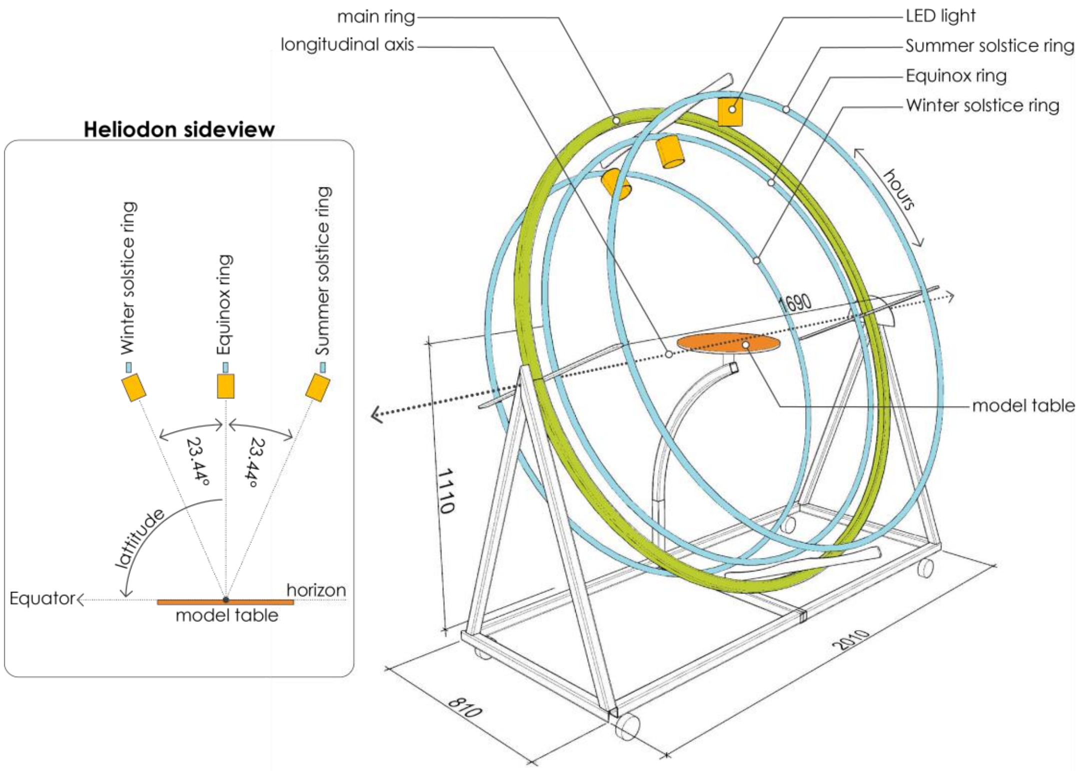

Fig. 2: Perspective drawing of the UL FGG heliodon with main dimensions given in mm.

3. Methodology

The study included an experimental and an experiential evaluation of the UL FGG heliodon emulator. For the purpose of the experimental evaluation, a comparison between the attained results using analogue (i.e. heliodon) and digital (i.e. computer simulation) methods for determining insolation was executed. Thus, the potential error in the accuracy of the heliodon was easier to evaluate. The results of both methods were used to identify the difference between the results obtained by computer and by the heliodon. Secondly, for the experiential part of the study, a comparison between the methods was evaluated using questionnaires handed out to the students during the spring semester of the 2017/18 academic year at the UL FGG and UL ZF. The focus of the questionnaires was to evaluate the students' opinion about the use of heliodon during the executed practical exercises. Additionally, they were asked about their preference at studying insolation – using the heliodon or, rather, computer simulations. Both experimental and experiential results were used to assess the usefulness of the heliodon as a teaching tool.

3.1 Experimental evaluation of heliodon

A simplified parallelepiped shaped building model with sides ratio of 1:1:2 (i.e. L:D:H) was tested at the geographical location of Ljubljana, Slovenia (46°3′N, 14°30′E). Both, digital model for computer simulations and equivalent physical models used for the heliodon analysis were made at various scales corresponding to realistic building size of 6 m x 6 m x 12 m. For the analysis, we selected three different sizes of models, namely small (scale of 1:400, corresponding model dimensions of 15 mm x 15 mm x 30 mm), medium (scale of 1:200, corresponding model dimensions of 30 mm x 30 mm x 60 mm) and large (scale of 1:100, corresponding model dimensions of 60 mm x 60 mm x 120 mm). The shadows cast by the described models placed under the heliodon were drawn on a standard ISO A3 format (i.e. 420 mm x 297 mm) paper and later scanned into a digital form. The results of computer simulations were also generated in such a manner as to correspond to the sizes acquired by the heliodon analysis. For the digital simulations, a plug-in software for Rhinoceros named DIVA (Solemma LLC, 2018) was used. An hourly shadow analysis was conducted by both the heliodon and computer simulations for each hour from 7.00 until 17.00, solar time, for selected critical days of the year when the shadows are more prominent (i.e. winter solstice and equinox). The evaluation of the acquired results was done by overlaying the simulated and emulated results and calculating the respective areas of shadows for each plotted hour. The simulated results were used as a reference for error (ERR) calculation and were considered to be 100% accurate. Therefore, heliodon ERR was determined using equation 1.

$$ERR = 100 - (\frac{A_{hel}}{A_{sim}} \times 100) \qquad \text{(eq. 1)}$$

Where ERR is error of the heliodon shadows in %; Asim is area of simulated shadows and Ahel is area of the heliodon shadows. ERR was determined for each scale (i.e. 1:100, 1:200 and 1:400) and for both analysed dates (i.e. winter solstice and equinox). However, only shadows that were entirely cast inside the projection area (i.e. 420 mm x 297 mm) were considered as relevant for calculating the average heliodon error. In particular, incomplete shadows were omitted from the average ERR evaluation. The expected heliodon error due to the non-parallel light source will be accentuated at the selected critical days as well as during early morning and late afternoon hours due to longer shadows caused by the low incident angles of emulated sunlight. Analogously, error will increase with larger scale or by moving the observed object from the centre of the heliodon.

3.2 Experiential evaluation of heliodon

One of the aspects of the experiential evaluation of a product or a tool is the usability testing. Performing usability testing greatly benefits users by minimizing or eliminating their frustration, because it exposes design issues, which can be improved (Rubin and Chisnell, 2008). An example of a questionnaire used to determine user satisfaction with a product they used is SUS, or System Usability Scale, which is also part of the ISO standard 9241 (Rubin and Chisnell, 2008). According to Brooke (Brooke, 1996), SUS is a quick, reliable, low-cost usability ten-item scale that can be used for global assessments of usability. The SUS is used immediately after the respondent had an opportunity to use the product and has to be filled before any debriefing or discussion takes place (Brooke, 1996). Each statement of the SUS has a five-point scale that ranges from "strongly disagree" to "strongly agree". The SUS scores have a range of 0 (negative) to 100 (positive), where scores under 50 would be found as not acceptable, scores between 50 and 70 as marginal and scores above 70 as acceptable (Bangor et al., 2009).

For the purpose of experiential evaluation of the UL FGG heliodon the described commonly practiced SUS questionnaire was used. In addition, an 11th question was added in order to asses user-friendliness according to the recommendation given by Bangor et al. (Bangor et al., 2009). The 11th question has seven point Likert scale that ranges from worst imaginable to best imaginable and is used as an adjective scale/rating. The questionnaire was divided into two sections.

USABILITY ASSESSMENT OF HELIODON TOOL

Please check the box that reflects your immediate response to each statement. Don't think too long about each statement. If you don't know how to respond, simply check box "3". Make sure you respond to every statement.

	Strongly disagree				Strongly agree
1. I think that I would like to use heliodon frequently.	1	2	3	4	5
2. I found heliodon tool unnecessarily complex.	1	2	3	4	5
3. I thought heliodon tool was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use heliodon tool.	1	2	3	4	5
5. I found the various functions in heliodon tool were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in heliodon tool.	1	2	3	4	5
7. I imagine that most people would learn to use heliodon tool very quickly.	1	2	3	4	5
8. I found heliodon tool very awkward to use.	1	2	3	4	5
9. I felt very confident using heliodon tool.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with heliodon tool.	1	2	3	4	5

11. Overall, I would rate the user-friendliness of heliodon tool as:

□ worst imaginable	□ awful	□ poor	□ neutral	□ good	□ excellent	□ best imaginable

1. In general I prefer using computer tools (simulation tools, CAD tools, etc.) rather than physical tools (models, sketching, physical plans, manual calculations, etc.).

□ I strongly disagree	□ I disagree	□ I partly disagree	□ I neither agree nor disagree	□ I partly agree	□ I agree	□ I strongly agree

2. In the case of insolation analysis at course Bioclimatic design I found using heliodon tool favourable over the computer simulation (SketchUp).

□ I strongly disagree	□ I disagree	□ I partly disagree	□ I neither agree nor disagree	□ I partly agree	□ I agree	□ I strongly agree

3. Please mark the most appropriate approach to achieving a sufficient understanding of insolation theory.

□ using solely computer tools	□ mostly using computer tools and only partly heliodon tool	□ an equivalent combination of both	□ mostly using heliodon tool and only partly computer tools	□ using solely heliodon tool

4. Which approach do you find more practical (circle the appropriate answer):

To carry out exercises (learning process): HELIODON TOOL COMP. TOOLS

To work in practice: HELIODON TOOL COMP. TOOLS

Fig. 3: Questionnaire on the usability assessment of heliodon tool (modified Brooke`s and Bangor's instrument).

The first section consists of 11 statements about usability of the heliodon. The second section consists of 4 additional questions about the comparison between the heliodon and computer simulations, where students stated their opinion and preference of using computer or physical tools (e.g. would they choose to use the heliodon over the use of computer (e.g. SketchUp) and which approach they find the most appropriate to achieve sufficient understanding of insolation, etc.). In the end, they were asked, which tool they would prefer using during learning process or when working in practice. The modified Brook`s and Bangor`s instrument is presented in Fig. 3.

A questionnaire-based study was conducted in order to qualitatively and quantitatively assess the usability of the UL FGG heliodon tool. The above described SUS was used for the measurement and evaluation of effectiveness and users` subjective reactions to using the tool (Bangor et al., 2009; Brooke, 1996). The unit of observation was an individual student at the UL FGG (N=15) and UL ZF (N=23), who participated at practical exercises (i.e. Bioclimatic design course, 3rd study year). The study period was April–May, 2018. All questionnaires were filled anonymously. Response rate was 100%.

4. Results

The results of the study are shown in the following two subsections. The first subsection represents the results of the heliodon accuracy evaluation conducted by comparing the differences between the insolation results obtained by computer simulation (DIVA) and those acquired by using the UL FGG heliodon tool. The second subsection contains the results of the heliodon usability assessment made by handing out questionnaires to the students after using the UL FGG heliodon during the educational process.

4.1 Experimental evaluation: Computer simulated insolation vs. heliodon acquired insulation

Experimental evaluation of the heliodon accuracy was conducted by estimating its accuracy by comparison of the simulated and the emulated results at selected hours for selected critical days at various scales. The error determination of the results is shown in Table 1. Shaded cells represent relevant error results (i.e. hour with full shadows in the projected area), which were used to determine the average error of the heliodon tool at various scales and at specific studied dates.

Table 1. Results of heliodon accuracy evaluation. Errors (*ERR*) presented in bold text were considered in the determination of average error, while shaded values were determined as useful.

		Hours (solar time)											
		7.00	**8.00**	**9.00**	**10.00**	**11.00**	**12.00**	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**	**AVG**
	Scale	***ERR* [%]**											
Equinox	**1:400**	48	**16**	**6**	**1**	**2**	**3**	**9**	**8**	**8**	**12**	31	**7**
	1:200	23	52	**27**	**17**	**13**	**22**	**28**	**28**	**34**	49	17	**24**
	1:100	2	20	28	**52**	**41**	**38**	**52**	**58**	36	12	15	**48**
Winter Solstice	**1:400**	/	21	**52**	**18**	**9**	**11**	**8**	**9**	**32**	11	/	**20**
	1:200	/	16	17	26	**28**	**34**	**67**	38	14	10	/	**43**
	1:100	/	18	22	15	17	20	14	13	17	/	/	/

The hourly error analysis showed that the most accurate insolation results acquired with the heliodon are around midday (i.e. 10.00 – 14.00), when the incidence angles of solar rays are relatively large (i.e. the Sun is high in the sky). Such conditions do not cause large inaccuracies of the emulated results, due the light source non-parallel rays. Analogously, error of the heliodon at winter solstice is almost double of that at equinox (Table 1 and Fig. 4), since shadows are longer and the error is magnified due to non-parallel light source. Figure 4 shows that some shadows at the model scale of 1:200 fall out of the projection area during the intervals from 7.00 to 10.00 and from 15.00 to 18.00, while at the 1:400 scale the intervals are shorter (Table 1). Thus, the calculated errors presented in Table 1 are inaccurate because A_{sim} and A_{hel} do not represent the total area of shadows during these intervals.

According to the conducted analysis it was found that the highest accuracy of the heliodon was at the scale of 1:400 for both analysed dates. The error at this scale was in the range between 1% and 16% (average: 7%) at equinox and 9% and 52% (average: 20%) at winter solstice. Error ranges for the former are between 8.00 and

16.00 and for the latter between 9.00 and 15.00. Expectedly, the least accurate results were acquired in the case of the model at the 1:100 scale at equinox, where the error inside the selected hours ranged from 38% to 58% (average: 48%). Overall accuracy of emulated shadows tends to decrease in relationship to larger scale of the model, to a point where the attained results are completely unreliable. Such case is the winter solstice with model at the scale of 1:100 (Table 1), where major portions of shadows fell outside the projection area. Therefore, the stated error of the heliodon (Table 1) is not realistic, because the largest differences occur at the end of the shadows, which are not recorded due to long shadows. The main reason for the decrease in accuracy of the heliodon with the increase of the model size lies in the non-parallel light source, the effect of which is accentuated at smaller scales. Moreover, the error also originates from the fact that the rotatable rings are not ideal circles, which are impossible to manufacture, nor can they be ideally mounted. Therefore, the distance between the LED light and the model table varies by ±3–5 mm.

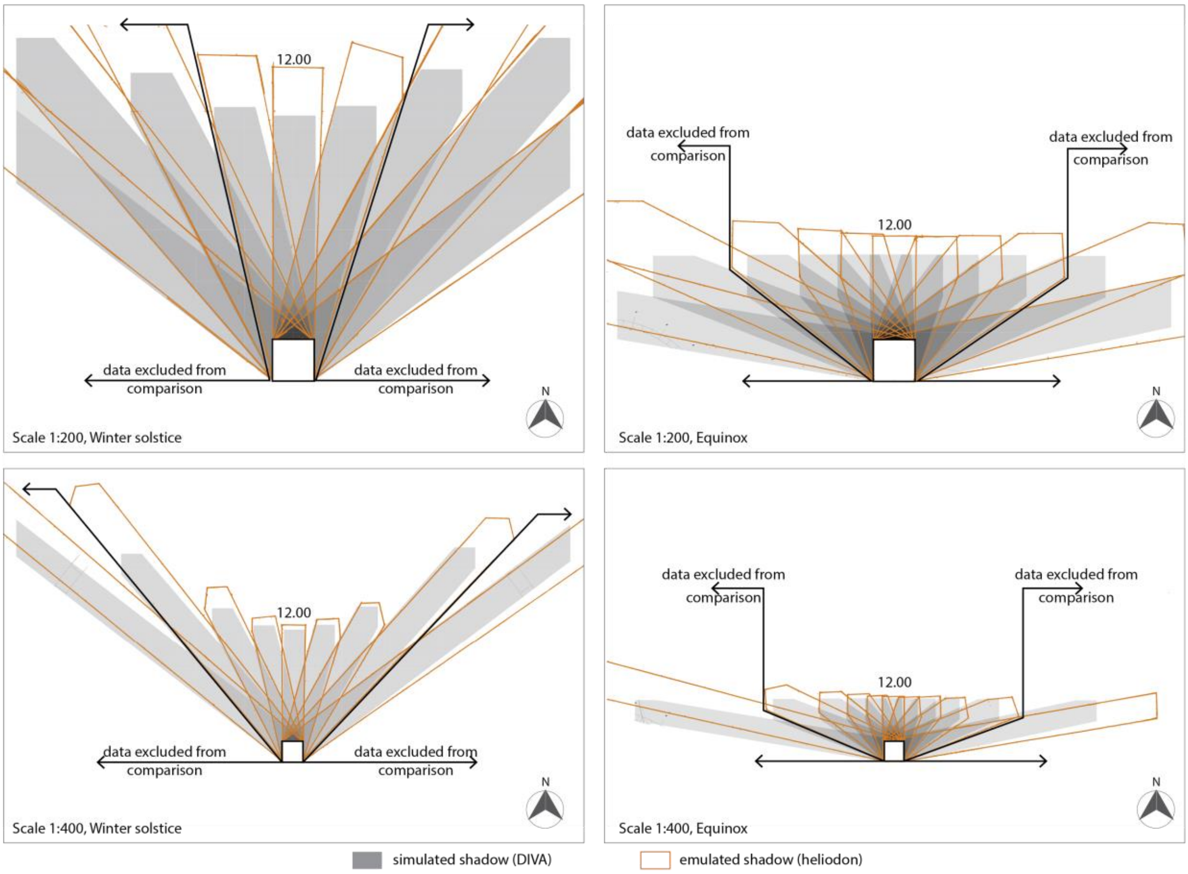

Fig. 4: Example of shadows acquired by heliodon and by computer simulations for winter solstice (left) and equinox (right) at 1:200 (top) and 1:400 (bottom) model scale.

The directionality of the shadows cast by the heliodon has been found to be satisfactory, since general directions of shadows at the observed hours are coincident with those of the simulations. Error in the direction of shadows tends to increase for early and late hours and is accentuated at winter solstice, again due to the non-parallel light source.

It was found that the UL FGG heliodon is most suitable for the use at smaller scales (i.e. 1:200 or smaller), because its accuracy is enhanced with the decrease of the model size. Furthermore, models at larger scales cast substantially longer shadows, meaning that they fall out of the projection area, reducing the practical applicability and usefulness of the heliodon analysis.

4.2 Experiential evaluation: Students' evaluation of heliodon as an educational tool

38 respondents (students) completed the survey. The majority of students (60.5%) were the UL ZF students and 39.5% of them the UL FGG students. Table 2 lists mean, median and SD scores. The SUS scores were in the range from 57.5 to 100. Mean SUS scores were higher for students from UL ZF (85.1) than for students from UL FGG (80.5). The quartile breakdown of study mean scores is shown in Table 3.

Table 2. Summary of SUS Scores.

Respondent	MEAN	MED	SD	Range
UL ZF	85.1	85.0	7.2	72.5–100
UL FGG	80.5	82.5	9.3	57.5–92.5
Total	83.3	83.8	8.4	57.5–100

In reply to the 11th question (adjective rating) "*Overall, I would rate the user-friendliness of heliodon tool as:*", the majority of respondents (68.4%) evaluated the usability of the heliodon tool as "*excellent*". That corresponds to mean SUS score of 83.3 (Table 4). 18.4% respondents of the total sample of users evaluated the usability of the tool as "*best imaginable*". This corresponds to mean SUS score of 86.1 (Table 4). Only 13.2% of respondents evaluated the usability of the tool as "*good*", corresponding to mean SUS score of 79.5. None of the users assessed the UL FGG heliodon tool worse than good.

Table 3. Quartiles for SUS Study Means Scores.

Quartile	Lower Bound	Upper Bound
1	57.5	77.5
2	77.5	83.8
3	83.8	90.0
4	90.0	100.0

If the adjective rating scores (i.e. the 11th question) are translated into 0–100 scale, the average score is 84.2. It is evident that the results of adjective rating very closely match the total mean SUS score (Table 2). Figure 3 presents individual SUS scores based on students of both faculties.

Table 4. Descriptive Statistics of SUS Scores for Adjective Ratings.

Adjective	Count	Mean SUS Score	Standard Deviation
Worst Imaginable	0	/	/
Awful	0	/	/
Poor	0	/	/
OK	0	/	/
Good	5	79.5	11.6
Excellent	26	83.3	7.6
Best Imaginable	7	86.1	8.0

On average, students partly disagree (i.e. –0.7 on the scale from –3 to +3) with the stated fact "I prefer using computer tools (simulation tools, CAD tools, etc.) rather than physical tools (models, sketching, physical plans, manual calculations, etc.)", which was surprising, because it was expected that they would prefer the use of computer tools. The disagreement was more significant for the UL ZF students (–1.2) and less for the UL FGG students (–0.1). In the sample, the majority of the students replied that in order to achieve a sufficient understanding of the insolation theory, an equivalent use of both, heliodon and computer simulations, is necessary. In reply to the question "Which approach do you find more practical to carry out learning process", 86.8% of students thought that heliodon tool was more practical for learning the process and only 13.2% thought computer simulation tools were better. At this question, there is no statistically significant difference between the two student populations. In reply to the question "Which approach do you find more practical when working in practice", the received total answers were 32.0% in favour of the heliodon and 68.0% in favour of computer software. Interestingly, there exists a substantial difference between the two populations. 56.5% of students from the UL ZF found computer tools more useful for work in practice, while the remaining 43.5% of students opted for the heliodon. Opposite to the respondents from the UL ZF, the majority of students from the UL FGG (86.7%) found computer tools handier for work in practice and the minority of students (13.3%) stated that the heliodon is more useful for work in practice.

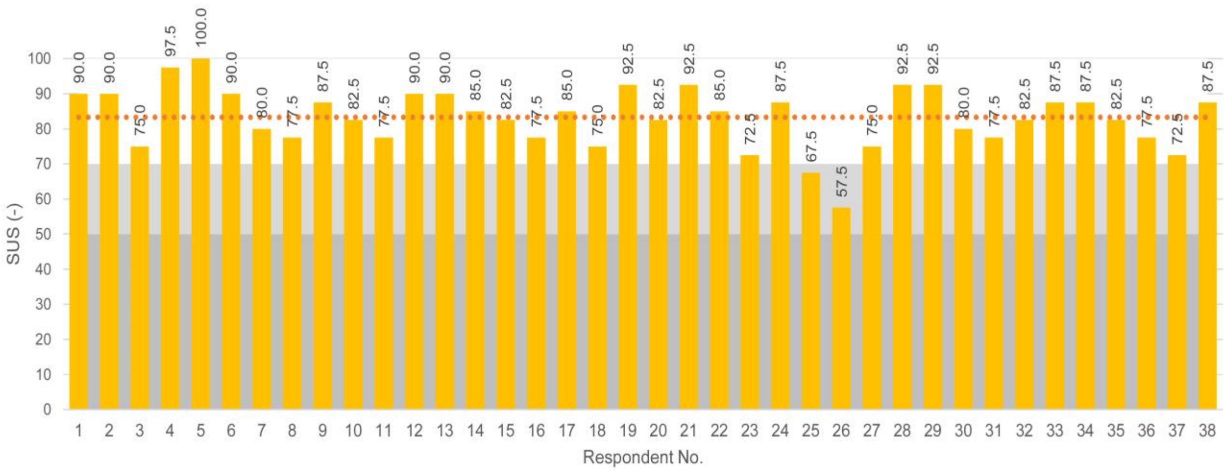

Fig.4: SUS scores for UL ZF students (N=23; x axis no. 1-23) and UL FGG students (N=15; x axis no. 24-38). Red line: Mean SUS score; white zone area: acceptable; light grey zone area: marginal, dark grey zone area: not acceptable.

5. Discussion and Conclusions

Student evaluation of the UL FGG heliodon gives evidence that it is a very useful educational tool, having no significant drawbacks, as relatively high average SUS score was achieved. The obtained objective SUS score is also in line with the scores of adjective ratings, where students assessed the heliodon user-friendliness mostly as "excellent". The attained SUS scores of the UL FGG heliodon can be compared to the SUS scores of a heliodon used at MIT (Osser, 2007), which was also a subject of a SUS survey among students (N=7). Their results ranged between 75 and 98, with an average of 84.6 and standard deviation of 8.6, indicating fairly favourable response. Osser's results are in line with the results of this study, with the difference in average SUS value being only 1.3 points. The results of our survey have also shown that students of both faculties (i.e. UL FGG and UL ZF) prefer a combination of both, heliodon and computer simulations, in order to achieve sufficient understanding of the insolation theory. The stated is in line with the results shown by Dubois et al. (Dubois et al., 2015), which highlighted that students value the opportunity to handle several types of tools rather than just one. Such use of combination of several tools is more likely to improve the knowledge and skills of students on issues such as climate change adaptation, where the understanding of solar geometry is important (Pajek and Košir, 2017). However, within the study made by Dubois et al. (Dubois et al., 2015) students stated that using the heliodon tool was less helpful due to the time required to build scale model necessary for the use of the heliodon. Additionally, they noted that the invested time was not justified in the light of lower precision of the results. The same issue was exposed by the experimental evaluation of the UL FGG heliodon in the present study, where concerns about the accuracy of the obtained results were exposed as substantial, especially with larger scale models. Therefore, the future of heliodon tools may lay in the development of advanced augmented reality tools, such as one presented by Sheng et al. (Sheng et al., 2011). However, it could be argued that for the use as an educational tool, the absolute accuracy of the heliodon is irrelevant for the presentation of the principle, where the accuracy of the obtained results is less important.

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