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DAYLIGHT WITHIN A ROOM IN THE EYES OF ARCHITECTURE STUDENTS

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Abstract

A questionnaire was conducted to investigate how 140 architecture students apprise daylight conditions within the classrooms. The participants were requested to evaluate the luminous environment and their luminous comfort. They were also asked about light preferences and knowledge on daylight metrics and regulations. The students' subjective appraisals results were compared with the experts' assessment and the on-site illuminance measurements. Later on, the students had to carry out a series of daylight indices simulations summarizing daylight conditions in their private rooms (a user's experience), and in a room, within a building, they had been designing (a designer's experience). The perception of the luminous environment was analysed against participants' comprehension of daylight simulations data. The issues students encountered during the daylight indicators analysis suggested that more coherent daylight education should be offered for future architects.

Keywords: Daylighting, Daylight Education, Questionnaire Survey

1 Introduction

Many lighting researchers focus on describing temporal, spatial and spectral characteristics of daylight through metrics which depict the image forming and non-image forming effects of light on humans. While the majority of architects put their efforts in creating spaces enhancing the quality of life. In doing so, their understanding of daylight semantics is crucial.

The motivation behind this study is an attempt to bridge a gap between lighting and architectural professions. The two disciplines often coexist with great design results, but sometimes, they do not thrive from each other knowledge (Yancey, 2010).

1.1 The uniqueness of the architectural and daylight education

For neither talent without instruction nor instruction without talent can produce the perfect craftsman (Vitruvius, 15-30 BC).

Vitruvius in his treatise on architecture, (Vitruvius, 15-30 BC) stated that architecture is the science arising out from many others sciences, and adorned with much and varied learning. According to him three principles of good architecture were:

- Firmatis (Durability) – It should stand up robustly and remain in good condition.
- Utilitas (Utility) – It should be useful and function well for the people using it.
- Venustatis (Beauty) – It should delight people and raise their spirits.

In the daylight science, the utilitas and venustatis principles have developed form daylight performance appraisals to daylight perception evaluations and their short and long-time repercussions on humans. The use of predictors based on photometric properties of daylight has historically been dominant in both research and practice. Thus, the human needs-centric approach was almost always a leitmotif for daylight parameterisation; the comprehension of human needs has continued to change following the discoveries. The fast development of daylight simulation models brought more questions on how to embrace the emotional impact of daylight through desirable by designers, by challenging to quantify, shadow, contrast, light composition patterns, and a view to the outside factors.

The complexity of architectural training and practice is well captured in Vitruvius's words. In attaining mastery cohesion of both the synthetic range of theoretical and practical knowledge and experience is necessary.

A good comprehension of daylight indicators allows the architect to use the daylight to create durable, functioning, and sustainable residential spaces. However, a designer has to be aware of the interdisciplinary discourse about daylight criteria and a rising number of various daylight visual and non-visual indices.

1.2 The challenges of daylight in architecture education

The daylighting design complements architecture design. Therefore, it should be and often is a part of architectural training. However, despite intensive research on how daylight multidimensionality is bound with human vision, psychophysiology, and health there are still insufficient data to support ultimate criteria for daylight within the built environment (Tregenza and Mardaljevic, 2018). Although often unsatisfactory, the mandatory daylight standards and recommendations are meant to support good practices to ensure the minimally acceptable conditions. The daylight criteria, tools and recommendations continuously improve, but they do not assure reasonable design solutions which come from architect's knowledge, craftsmanship, experience, intuition and training.

Throughout the years of architectural history, daylight design was an integrated part of architecture planning and results of an architect's capability to comprehend and envision building masses in sunlight and skylight. However, in recent years' daylight performance simulations and daylight evaluation started to be considered as highly specialised tasks. Many universities offering architectural undergraduate and postgraduate degrees recommend classes on daylight in architecture or solar energy for urban planning as non-mandatory extracurricular studies or CPD - Continuing Professional Development Courses (IEA SHC Task 51, 2017). This approach resulted in limited daylight courses, offered within the mandatory architecture curricula (Giuliani et al., 2018).

Another challenge is a vast number of daylight simulation metrics and tools available. Reinhart and Fitz, while surveying architects and engineers on the use of daylight simulation in building design, found out that among those, who claimed using computer simulation tools for daylighting design 42 different simulation programs were used (Reinhart and Fitz, 2006). Due to recent findings on the non-image-forming (NIF) effects of light, a number of the new daylight indices has been rising. Despite constant progress, researchers admit that there are still many challenges to accurately depict spectral and time-dependent factors influencing daylight performance and its wide-spectrum-impacts on humans (Andersen, 2015; Solt et al., 2017). The new daylight parametrisation concepts affect the design of the built environment, especially regarding solutions on a building envelope, its orientation, smart glazing or integration of daylight with electric light (Solt et al., 2017). Therefore, a need for modern daylight education for architects is expressed.

1.3 The survey and the appraisal tasks background

The literature review findings pointed out to several contemporary publications on daylight symbolism and aesthetics in Polish architecture. With the exception of sources intended for building physics experts, there were no many publications on daylight performance metrics. The daylight design classes rarely appear in curricula of 34 universities and schools offering architectural bachelor (BSc) or master (MA) courses in Poland.

The survey was proposed to verify the findings that the offered daylight education for architects is limited in Poland. The objectives were to investigate what kind of daylight design tools were architecture students familiar with and how they would implement them into an assessment of daylight conditions. The research involved 140 postgraduate architecture students from three architecture schools. The main aim was to identify the gaps in daylight education for future architects in Poland.

Regarding the rationale behind the design of the study, the analysis of the questionnaire results and responders' comments tested the feasibility of the questions, their arrangement and clarity as well as helped to identify the primary educational deficiencies — this data allowed to design the appraisal assessment tasks. The interdisciplinary character of this study was also a prerequisite for the pilot questionnaire followed by the daylight qualities assessment tasks. The purpose of this approach was to find out what are the necessary qualities or abilities among future designers that may be developed and lead to future implementation of modern daylight design appraisals techniques into architectural training.

2 Methods

The research methods include:

- The pilot study assessment of daylight performance within a given space (classroom) via a paper questionnaire taken during the class hours.
- An assessment of daylight performance within a room of a residential dwelling based on a student-user's experience but including an analysis of daylight requirements found in Polish housing regulations on distances between buildings, window design, window-to-floor ratio (WFR) and insolation times.
- An assessment of daylight performance within a room of a public building designed by a student, based on the designer's experience but following the daylight design legislative requirements.

While appraising daylight luminous environment within the classrooms students were asked questions on a subjective perception of the daylight characteristics, preferences towards daylight, and knowledge on daylight metrics, and regulations. In private dwellings, students observed and evaluated daylight conditions within their rooms using chosen daylight performance simulation tools. This task enabled them to compare the produced daylight simulations results with their end-user experiences. During the analysis of daylight characteristics within a room of a designed building, the participants had to answer inquiries on how daylight appraisals findings had impacted their design decisions as well as, how the current daylight recommendations influenced their design.

2.1 The pilot study

The paper questionnaire consisted of a range of open and Likert-type scale questions arranged into four main parts (Figure 1):

- A: general information about the space and the responders including room measurements and simple calculations of the window to floor ratio (WFR); sketch diagrams and plan section of the room with a position of a student marked on it.
- B: Perception of the luminous environment, the evaluation of a daylit environment took place in the selected classrooms The responders were asked about perception of daylight in a context of the physical properties of the interiors, ways of providing daylight within a space, daylight control and the luminous comfort in association with a visual task they were performing. During students' assessments, the so-called experts completed the perception part of the questionnaire, took on-site illuminance measurements along with photo documentation to investigate their correlations with the responders' opinions.
- C. Daylight knowledge: open questions were used to investigate: daylight lighting indicators, methods and tools of daylight performance simulations, daylight regulations.
- D. Preferences including subjective responses to open or multiple-choice questions on preferences on colour, intensity, and photometric characteristics of daylight; the best and the worst examples of daylight design in architecture; the ways to bring daylight into the different interiors.

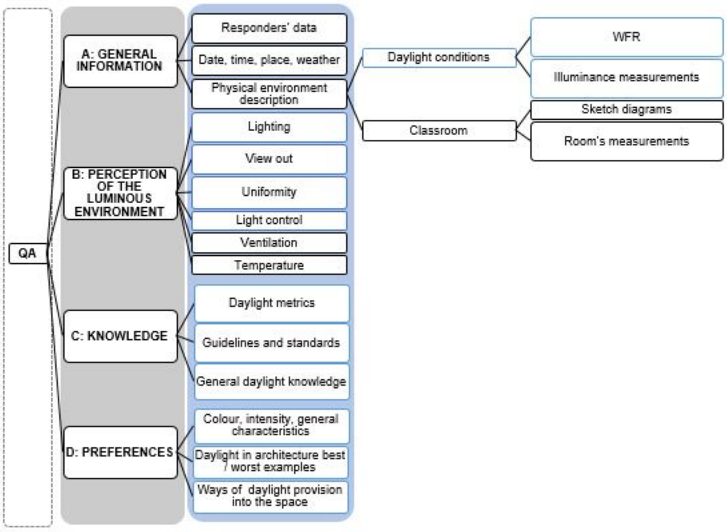

Figure 1 – The content and rationale for the pilot study questionnaire

The physical measurements of the room, window-to-floor ratio calculations were done by a whole group of students to shorten the procedure. The on-site illuminance measurements were taken by the lecturer or the researcher (the experts) using a UNI-T 381 illuminance meter at six different places within a room. The values do not reflect the constantly changing daylight spectral characteristics. The whole procedure usually took 30 to 40 minutes. Because the questionnaire was in English, terms like daylight uniformity, glare, veiling reflections were explained in Polish before each of the sessions.

2.2 Daylight within a private dwelling - assessment task

The assessment of daylight-related attributes within students' private dwellings contained an analysis of the location and orientation of the building, as well as, a description of façade finish, apertures, glazing types and shading system. The photo documentation, drawings and a description of the selected physical features of the chosen spaces with an empathise on daylight provision, an evaluation of the view (based on CIE EN 17037 standard), interior finishes were also provided. The students were asked to performed daylight performance simulation illustrating the insolation times, luminance and illuminance values on the equinox and solstice days for different hours during the chosen days. The average daylight factor (DF) values were also calculated. The main objective of the appraisal task was to analyse the results of daylight performance simulations and confront them with the student-user's observations. The choice of daylight assessment tools and simulation software was up to the participants.

2.3 Daylight within a room of the designed public building

The analysis of the daylight characteristics within a chosen space of the planned building in the majority of cases portrayed a daylit classroom within a school designed for the mandatory design course. The daylight appraisal was based on luminance, illuminance and the average daylight factor simulation results in a context of proposed daylight design solution (glazing, apertures design, daylight control systems, etc.) The choice of the tools and daylight assessment methods were suggested by a student-designer.

3 Results

3.1 The pilot work questionnaire chosen results

Form the group of 140 participants; all students provided statistical information about themselves. Three-quarters of responders were women. Eighty-four per cent of students were 20-30 years old, while 14 % were 30-40, 2 % were older. Only 112 students assessed the daylight conditions, answered knowledge and preferences questions. The participants were all architecture students from two state-owned technical universities and one private school of applied science. In all classrooms the WFR was above 1:12 and the average DF was > 2 %. The majority of assessed classrooms had white ceilings and walls covered with different architectural drawings and wood (oak) or grey floors. The luminance measurements taken by the expert demonstrated various values depending on the external conditions and were used to verify the expert subjective daylight appraisal. The questionnaires were taken in seven different classrooms under changing weather conditions, on different hours and days of the year.

3.1.1 Appraisal of daylit rooms and daylight knowledge

There were no statistical differences between the expert's and the students' daylight conditions evaluations. Forty-four per cent of students was dissatisfied with the view out, but only 13 % rated the daylight provision as poor. The main reasons for dissatisfaction with the outside view were nearby obstructions. Only 34 % of architecture students were able to name any daylight lighting indicator. While 10 % participated in a project where daylight performance simulations were done. The methods for appraising daylight conditions concerning the form of the residential building were described by 41 % of responders. Almost 64 % of participants could not name any daylight regulation. Another 32 % had a brief knowledge that daylight was mentioned in Polish building standards. Seventy-six per cent of respondents could not name any lighting regulation.

3.1.2 Daylight preferences

Daylight was named as a favourite type of light by 63 % of all surveyed students. Eighty-five per cent of students believed that combining electric lighting schemes with daylight design would contribute to energy savings. Daylight was expected to help to create a pleasant atmosphere within a space by 76 % of respondents. Sixty-two per cent of students felt that daylight should provide as much free light as possible. Forty-three per cent would expect daylight to replace electric lighting and 40 % believed that daylight solutions should be energy-efficient Almost 36 % could not provide any best or worst example of daylight design in the contemporary architecture.

3.2 Daylight within private rooms and designed classrooms appraisal results

Analytical and design exercises included a group of 60 students who had previously taken the questionnaire. All students received 20 hours’ daylight introductory course. The analysis of the physical characteristics of the rooms in question, as well as a description of how to introduce daylight into space, were executed without any problems. One-third of the students performed shadow analysis in SketchUp. This program was also the most frequently used program to carry out simple simulations of insolation within the investigated rooms room. The software chosen for luminance, illuminance and daylight factor simulations was Daylight Visualizer 2.

Half of the respondents had difficulties in synthesising the conclusions from the daylight performance simulation analysis especially regarding the received values of L, E or DF against their observations from the user's position. The obtained results of shadow analysis corresponded well with the users’ experience. The daylight improvements applicable to the investigated spaces and suggested by the students were limited to the various types of shading systems or the internal walls’ colour changes. In a case of the daylight evaluation in the designed rooms, an apprehension of simulated average daylight factor, luminance or illuminance values was limited. In three-quarters of cases, the proposed building’s design followed aesthetics more than daylight analysis conclusions. When students were asked for daylight design solutions to tackle the observed issues like low DF values or possible glare or thermal problems, 90 % of them indicated only the use of internal shading. The results obtained from the design exercises demonstrated limited knowledge of modern daylight technologies and a lack of practical comprehension of day-lit environment characteristics.

3.3 Overall results

The data obtained during the first and second phase of the study indicated students’ shortcomings in the ability to analyse and synthesise the daylight observations and applying them into the design process. The respondents coped well with the description of the existing lighting conditions. However, they reported difficulties in understanding the terminology related to the parameterisation of daylight and the understanding of the boundary conditions suggested by the existing daylight regulations. Despite students' fluency in architectural modelling and their familiarity with the chosen design tools, most of them performed daylight performance simulations for the first time. They often commented on their lack of understanding of the basics of lighting analysis while interpreting the simulations results.

The statistical analysis of the students' answers illustrated that the knowledge of daylight modelling parameters influences the ability to critically interpret the observed lighting conditions and apply the conclusions into the design.

4 Discussion

4.1 The pilot work discussion

4.1.1 Statistical information about the responders

The three-quarters of the group were females. However, no statistically significant difference was found on perception, preferences and knowledge results between females and men in this study. Although some other researches, who carried out surveys on feelings on luminous comfort did not find the gender-related statistical difference (Xue et al., 2014), it is still a matter to investigate more thoroughly. Also, to ensure objectiveness, the participants were students from three different universities yet, this fact was not analysed further.

The majority of responders were between 20-30 years old, whereas the experts (tutors or lighting researchers accompanying responders at classrooms) were considerably older (30-50). The perception of daylit environment can change with age; thus, due to a modest number of experts (1 to 2 per sessions), this matter was not examined further.

The responders' feelings and satisfaction with daylight conditions depended on physical characteristics of the surrounding spaces, as well as on the particular daylight conditions depending on the time of day and year. Those attributes were described and recorded. However, a comparison of their physical appearance and photometric characteristics of the described daylight scenes are not presented in this paper due to its different scope of objectives.

4.1.2 Issues with measuring the human perception of daylight

The visual comfort, daylight luminous comfort (Xue et al., 2016), daylight satisfaction (Galasiu and Veitch, 2006; Galatioto and Beccali, 2016), as well as a well day-lit space attributes and indices are still ambiguous concepts which relate to various luminous conditions depending on viewer's subjective perception, preferences and knowledge. Due to the constant changes in temporal, spatial and spectral characteristics of daylight, scientific comprehension of visual and non-visual comfort relates to the illumination levels, (Bodmann, 1992; Nabil and Mardaljevic, 2006), luminance patterns, (Loe et al., 2000; Van Den Wymelenberg et al., 2009), uniformity or contrast (Rockcastle et al., 2017), satisfaction with visual environment (Veitch, 2001; Galasiu and Veitch, 2006), the anti-glare measures (Wienold and Christoffersen, 2006; Wienold and Bodart, 2018), a control of daylight provision including various shading system control (Wong and Istiadji, 2004; Konis, 2013), the bio-responses correlated with ipRGCs (Lucas et al., 2014), an access to view and view ratings (Boyce et al., 2003; Tuaycharoen and Tregenza, 2007; Veitch and Galasiu, 2012), the aesthetics and a visual perception of light spaciousness (Johansson et al., 2010). The researchers propose different qualitative and descriptive methods illustrating the human perception of daylit space characteristics. Due to a vast number of possible light appraisal paths like linked mechanism maps and vision paths (Veitch et al., 2008; Veitch et al., 2011) and daylight evaluation indices and methods (Galasiu and Reinhart, 2008; Galatioto and Beccali, 2016; Bonomolo et al., 2017; Giarma et al. 2017) the survey contained question referring to selected aspect of daylight quality criteria found in standards and environmental performance assessment frameworks like lighting control, aesthetics, uniformity, glare, control or window views ratings. The received results indicated that there were no statistically significant differences in daylight evaluations between the experts and the students. This finding was later confirmed during the follow-up international study based on the revised questionnaire QA DAY.KE (DAYlight Education and Knowledge in Europe) (Giuliani et al., 2018), which was held internationally and based on the data received from 600 students.

The main reasons for dissatisfaction with daylighting within classrooms were a lack of interesting views, glare, limited control of daylight (the internal blinds control). The importance of a view factor and its boundaries is still a subject of many studies. Farley and Veitch (Farley and Veitch, 2001) re-examined several studies on the complicated relationship between personal preferences, well-being, productivity and health and demonstrated positive relations between windows natural views and occupants' well-being and health. Daylight control is linked with glare and visual and thermal discomfort. These factors are described in relevant literature as major contributors to residents or workers' dissatisfaction with daylight and many scientists try to estimate boundary conditions and quantification frameworks for these daylight related indices (Van Den Wymelenberg et al., 2009; Boyce and Wilkins, 2018; Pierson, 2018; Wienold and Bodart, 2018).

Though, students asked many questions indicating that they lacked an understanding of concepts like daylight uniformity, glare, control of daylight, colour perception. The reactions to daylit spaces, an ability to recognise excessive daylight, glare and thermal discomfort among the group were similar, despite differences in educational backgrounds, preferences. Reinhart et al. (Reinhart et al., 2014) findings on assessing the relation between intuition and perception of daylight conditions of the physical environment versus digital analysing methods (simulations) done by students from different countries and climate zones, were more complicated. Also, later DAY.KE results indicated possible differences in daylight appraisal between people with different cultural and climate backgrounds (Giuliani et al., 2017).

4.1.3 Preferences

The preference for daylight was expressed by 63 % of responders. The fact that many people indicated a preference for daylight rather than electric light is well documented by other researchers (Veitch et al., 1993; Galasiu and Veitch, 2006). The students' expectations for daylight were to create a pleasant atmosphere, to give as much free light as possible and to provide a view outside. These expectations relate to general criteria for the assessment or visual comfort provided by the multi-criteria green assessment systems (Giarma et al., 2017) or latest daylight standards (Mardaljevic and Christoffersen, 2013).

4.1.4 Knowledge

The survey provides clear insights about students' daylight knowledge on daylight metrics and regulations. Respectively 66 % and 64 % of the responders could not name any of them. The other worrying results were that only 10 % of students participated in the project where daylight metrics had been used. Consequently, 53 % could not indicate good daylighting design implementations within the built environment. Thus, 45 % of responders would receive more education on daylit in architecture. One of the main outcomes of the questionnaire it that the results illustrate students' fragmentary education on daylight metrics, appraisal methods and regulations in Poland. Due to a lack of similar studies, it is difficult to verify these findings thoroughly. The received results combined with the data collected from other European universities during DAY.KE project indicated that daylight knowledge and comprehension vary substantially among the students from the universities where daylight education was a mandatory part of architecture curriculum, and the students form the schools where this was not a case (Giuliani et al., 2018). Nevertheless, looking at the latest educational initiatives held by the CIE (a proposal for renewal of CIE Publication No. 99: *Lighting Education: 1983-1989*), the Daylight Academy support for publication targeting interdisciplinary researchers (Sanders and Oberst, 2017) and IEA SHC (new reports) a reinvention of daylight training is necessary.

4.2 The private rooms and designed rooms daylight appraisal discussion

On the one hand, an acceleration of new computational tools is suitable for a designer due to the growing accessibility of the software which offers sunlight or skylight luminance analysis. On the other hand, the number of daylight simulation programmes can overwhelm and confuse an architect. Reinhart and Fitz, (Reinhart and Fitz, 2006) while surveying architects and engineers on the use of daylight simulation in building design, found out that only 51 out of 185 responders admitted that they had not used computer simulations for their daylight analysis. The data collection took place in 2003 and 2004. Therefore these results could be outdated. The assumption that the current use of the computer simulation tools for daylight analysis, mainly including the dynamic and NIF indicators, has been growing should be considered.

Notwithstanding, Reinhart and Fitz study indicated that among those individuals who had not been using computer for their daylight simulations the reasoning supporting this behaviour were due to lacking knowledge which tool to use, a lack of training (own or staff), a demanding training (long time), the client's unwillingness to pay for the service and the cost of the tools-too expensive. The three of these factors were also mentioned by the students when asked about their use of daylight performance simulation tools. The same study (Reinhart and Fitz, 2006) indicated that among those, who had claimed using computer simulation tools for daylighting design 42 different simulation programs were mentioned. This number of the software in use, indicated, development and variety of such tools, but also revealed divisions between the community. Although one of the often-mentioned tools was Radiance, this software was considered too advanced for this study, due to the results gathered during the pilot study. None of the surveyed Polish architecture students indicated Radiance as a known tool. This result may be heavily impacted by a lack of up-to-date daylight textbooks and training.

According to the pilot work participants SketchUp was the most popular tool during the initial and design phases of planning. It was used for rudimental shading evaluation outside the buildings, as well as for the assessment of sunlight provision within investigated rooms. The sunlight provision images generated by the students using SketchUp give basic information of sunlight geometry within the spaces at different times a day at various days per year. Thus, they do not indicate any photometric values, according to the responders. They were useful for simple assessment of openings geometry, façade design and dwellings layout evaluations. The simulation of DF, luminance and illuminance were performed by students using Daylight Visualizer 2.0, a tool validated against the CIE 171: 2006 *Test cases* (Labayrade et al., 2006) and verified during several daylighting studies (Iversen et al., 2013; Mohelnikova and Hirs, 2016). DV2 calculates luminous distribution using the ray-tracing method. The images generated by the participants were displayed as colour images with numerical values and contour plots and embodied the chosen daylight indices DF, L and E, which well depicted the dynamics of changing daylit conditions inside the rooms. Students apprised this tool as a user-friendly, but the received results required the skills and knowledge to interpret them. The students were confused while assessing values of daylight metrics and types of CIE skies. They also struggle to remember that the simulation-based approximate results were not real-life values.

5 Conclusions

In conclusion, the obtained results of the conducted direct questionnaire and the appraisal tasks illustrate the following tendencies:

- perception of quality related to daylight by the students in the given rooms was intuitive and coincided with the observations made by supervising expert and the recorded measurements of light intensity levels
- despite diversified educational offers, the participants of the survey demonstrated a low apprehension on daylight indicators and analysis methods

The results of the design analytical tasks indicate:

- the tendencies to read computer simulations as factual rather than theoretical, presumable or probable
- issues with the synthesis of findings from received simulations data
- an inability to critically explain the differences between the obtained results and own observations
- problems in applying the simulations conclusions into the design solutions

To create the modern built environment when smart daylight solutions are used a synthetic range of theoretical and practical knowledge and experience exchange is necessary. The daylight appraisal tasks confirmed gaps and deficiencies in daylight education for architecture students, especially in a context of the interpretation of the computer simulations results of the selected daylight indicators. The majority of responders were not able to transfer the results of daylight analysis into the design solutions. The students demonstrated significant interest in daylight assessment tools, yet expressed their confusion about a vast number of daylight indicators and appraisal tools available. Nevertheless, the modern daylight assessment techniques and design solutions should be taught and explained to future architects, in a way to help them to make the right design solutions, which enhance human life within the buildings.

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