Architecture and Planning Journal (APJ)

Volume 28 Issue 3 *ASCAAD 2022 - Architecture in the Age of the Metaverse – Opportunities and Potentials*
ISSN: 2789-8547

Article 13

March 2023

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Recommended Citation

BELOK, FATIMA; KHALIFA, MOSTAFA; EL-BASTAWISSI, IBTIHAL; and HANAFI, MOHAMAD (2023) "DIGITAL FRAMEWORK TO OPTIMIZE VISUAL COMFORT USING KINETIC FACADES," *Architecture and Planning Journal (APJ)*: Vol. 28: Iss. 3, Article 13.
DOI: https://doi.org/10.54729/2789-8547.1208

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Abstract

Visual comfort is one of many aspects of human comfort that should be considered in architectural spaces. Visual comfort is an architectural necessity and could be achieved and optimized in spaces through controlling facades' opening. This could be achieved by applying kinetic facades, which is one of the trends in the field of responsive architecture. However, the research' s aim is optimizing visual comfort using kinetic facades in educational spaces. This optimization will improve the environmental quality of the educational space. In this research architects will achieve easily more effective kinetic facades to have better visual comfort by enhancing daylight quantity and quality using luminous environmental parameters' measurement tool. In this research a series of scripts will be applied on various kinetic facades' alternatives. These scripts will be based on a relation between different daylight and kinetic parameters. Thus, the outcome is to develop an Add-on, as a digital plugin, that will be presented through a friendly Graphical User Interface (GUI).

Keywords

Visual comfort, daylight, educational spaces, kinetic facades, Add-on.

DIGITAL FRAMEWORK TO OPTIMIZE VISUAL COMFORT USING KINETIC FACADES

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ABSTRACT

Visual comfort is one of many aspects of human comfort that should be considered in architectural spaces. Visual comfort is an architectural necessity and could be achieved and optimized in spaces through controlling facades' opening. This could be achieved by applying kinetic facades, which is one of the trends in the field of responsive architecture. However, the research' s aim is optimizing visual comfort using kinetic facades in educational spaces. This optimization will improve the environmental quality of the educational space. In this research architects will achieve easily more effective kinetic facades to have better visual comfort by enhancing daylight quantity and quality using luminous environmental parameters' measurement tool. In this research a series of scripts will be applied on various kinetic facades' alternatives. These scripts will be based on a relation between different daylight and kinetic parameters. Thus, the outcome is to develop an Add-on, as a digital plugin, that will be presented through a friendly Graphical User Interface (GUI).

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ملخص

الراحة البصرية هي واحدة من العديد من جوانب راحة الإنسان التي يجب مراعاتها في الفراغات المعمارية. تعتبر الراحة البصرية ضرورة معمارية ويمكن تحقيقها وتحسينها في الفراغات من خلال التحكم في فتحات واجهات المبانى. يمكن تحقيق ذلك من خلال تطبيق الواجهات المتحركة، والتي تعد واحدة من الاتجاهات في مجال العمارة المتجاوبة. ومع ذلك، فإن هدف البحث هو تحسين الراحة البصرية باستخدام الواجهات المتحركة في الفراغات التعليمية. سيؤدي هذا التحسين إلى تحسين الجودة البيئية الفراغات التعليمية. في هذا البحث، سيحقق المعماريون واجهات حركية أكثر فاعلية بسهولة للحصول على راحة بصرية أفضل من خلال تحسين كمية وجودة الإضاءة الطبيعية باستخدام أداة قياس المتغيرات البيئية المضيئة. في هذا البحث، سيتم تطبيق سلسلة من البرامج النصية الحوسبية على بدائل مختلفة للواجهات المتحركة. ستستند هذه البرامج النصية إلى العلاقة بين متغيرات الواجهات المتحركة ومتغيرات الإضاءة الطبيعية المختلفة. وبالتالي، فإن نتيجة البحث هي تطوير مكون برنامج إضافى رقمي يتم تقديمه من خلال واجهة مستخدم رسومية سهلة الاستخدام.

الكلمات المفتاحية: الراحة البصرية، الإضاءة الطبيعية، الفراغات التعليمية، الواجهات المتحركة، مكون برنامج رقمى إضافى.

1. INTRODUCTION

Achieving comfort in a space is related to physical environments, in addition to psychological issues, mood and social factors (Kamholz & Storer, 2009). Visual, audio, thermal and hygienic are all factors that could affect the human comfort in a space. This research will tackle just visual factor.

Optimizing visual comfort is considered an important factor in human comfort, by using stained glass, blinders and various types of shading devices, which were manually controlled. In addition, kinetic architecture especially kinetic facades have been emerged through the past decade in the field of architecture and visual comfort (Al Horr et al., 2016). Thus, this research focuses on achieving visual comfort in educational spaces, especially in universities library

The research problem is that various software can do environmental simulation to achieve visual comfort in a space. Few of them can simulate kinetic facades at different situation. Thus, the aim of this research is to create and evaluate an Add-on software to enhance a digital tool, to facilitate the simulation and optimization process for architects, when using kinetic facades which in turn will optimize visual comfort through a Graphical User Interface.

The research methodology will start by doing a literature review about visual comfort and kinetic parameters in educational spaces focusing on illuminance and glare, then exploring ladybug and honeybee as digital environmental tools. Proposing and Add-on that can be universally applied and used, the next step is verifying and evaluating the developed Add-on and applying it at BAU university library, in Tripoli campus, as a case study. The last step is enhancing the (GUI) of the proposed Add-on after evaluation.

2. DAYLIGHT AND KINETICS SYSTEM IN UNIVERSITIES LIBRARY

Lighting can reinforce action and perception, according to the illumination Engineering Society of North America (IES). Productivity, human health and energy efficiency are all affected by daylight (El-Dabaa, 2016).

- Energy efficiency: more efficient daylight reduces the need for artificial light, resulting in lower energy consumption.
- Functional efficiency: sufficient lighting improves spatial and functional efficiency of space, not only in the direct use such as writing but also in term of revealing color and form that promote functional efficiency.
- Human productivity and health: According to Tomassoni adjusting daylight amount in a location improves user mood and productivity. Because psychological well-being, body temperature and brain activity are all influenced by the light in a certain architectural context, studies reveal that those who work at night have a significantly higher negative mood that those work during the day (Tomassoni et al., 2015). If the daylight amount is insufficient, their neutral system may be disrupted, leading to a feeling of exhaustion.

The European Norms (EN) set the universal standards for light planning in indoor work environments, which were adopted by the European Committee for Standardization (CEN). These guidelines aid in achieving human visual comfort in a variety of settings and functions (EN, 2011). Sufficient lighting is required for both quantitative and qualitative components of comfortable daylight.

As a result, the research focuses primarily on the visual comfort category, which comprises numerous characteristics for establishing the luminous environment, such as luminance and glare, which are further investigated.

2.1. Luminous Environment Parameters

The primary elements affecting daylight and artificial light, such as illuminance, glare, luminance distribution, directionality of light, variability of light, flicker, color rendering, and color appearance of the light, determine the luminous environment (EN,2011).

It is remarkable that glare and illuminance are two of the most important parameters for having comfortable daylight and sufficient daylight quantity and quality, according to European Standards (EN). Thus, the two parameters considered in all of the research are illuminance and glare.

- Glare

When bright spots develop in the visual field, glare occurs. Glare that is distracting might lead to accidents and tiredness. As a result, various criteria must be considered in order to minimize unacceptable glare, such as Daylight Glare Probability (DGP), a method that considers both "illuminance at eye level and individual glare sources of high brightness to predict the fraction of unsatisfied persons" (EN,2011). DGP is divided into four categories: not perceived glare, perceived but not disturbing glare, disturbing glare, and intolerable glare. The first two are deemed suitable, while the final two are considered unsuitable.

- Illumination

Illuminance has an impact on people's visual comfort and how quickly they perceive visual activities. The European Standards established illuminance values based on the type of work environment and requirements for performance and comfort (EN, 2011). Illuminance levels should be higher than or comparable to those specified in European standards. Illuminance values should be calculated at particular spots, which should be produced using a grid system with equal sides. The ratio of length to breadth varies between 0.5 and 2. In addition, the number of grid points and the distances between them should be provided based on EN standards from 2011.

2.2. Kinetic Façade & Importance

The layer located between inside and outside a building is called building envelope, which could be static or dynamic. Blinders or shadings located on a building façade could be kinetic, which mean the movement, while kinetic architecture mean the building design produced by a movement. In addition, kinetic architecture is one of the most significant trends in architecture, since it is a revolution from static to dynamic (Al Horr et al.,2016). From 1970 to the present, many researchers have discussed kinetic architecture, including Zuc and Clark in 1970, Michael A. Fox in 2003, Chuck Hberman in 2005, Robert Kronenburg in 2007, Kostas Terzidis in 2008, and others (Barozzi, 2016). Furthermore, Kostas Terzidis suggested in 2008 that adding motion to a building is vital since it affects the design, aesthetic, and performance of the structure. As a result, kinetic architecture is more than simply about moving buildings; it's also about bridging the gap between nature and the built environment in terms of environmental variability.

Furthermore, depending on the system's function, kinetic architecture takes on several forms (Rossi et al., 2012). It could, for example, be used on building facades, building structures, and landscapes, among other things. The research will target kinetic facades that could be controlled automatically in response to outdoor environmental changes such as daylight. Kinetic facades could be found in many examples in the world, such as Abu Dhabi Investment Council HD in Abu Dhabi, Kiefer Technic Showroom in Austria, the University of Southern Denmark (ADU), Arab World Institute in Paris, and other.

3. DAYLIGHT SIMULATION PLUGINS (LADYBUG AND HONEYBEE)

For environmental simulation, various simulation plugins have been utilized; however, this study uses the ladybug and honeybee plugins in grasshopper3D for Rhino since they are validated and built on validated energy and daylighting engines, EnergyPlus, Radiance, and Daysim (Sadeghipour Roudsari and Pak, 2013). Python, one of the most powerful programming languages, is used to script Ladybug and Honeybee (Ladybug Tools | Ladybug", 2020). Ladybug allows users to import standard EnergyPlus Weather files (EPW) into Grasshopper, as well as other diagrams and studies such as sun path, radiation rose, wind rose, shadows studies, view studies, and others.

Following an examination of the existing plugins, the following features have been identified as having the potential to provide better, more flexible, and user-friendly performance that will eventually answer to research objectives:

- Kinetic simulation automation: present plugins waste a lot of time because when architects simulate dynamic yearly shading, they have to work under certain constraints: each instance must be done independently and continuously by the user. As a result, it is necessary to simulate diverse kinetic scenarios automatically over time.
- Adding a time range: the simulation given by the existing plugin is only for a fixed time annually. As a result, a long-time range is required to automatically replicate different periods of time throughout the year.
- Output graphical interface: the existing plugins only include graphs for static shading cases as outputs, but no graphs for kinetic shading situations, such as graphs for shadings at different angles.
- Multi-task simulation: Furthermore, the present plugin only works with one simulation type, such as illuminance; it is not feasible to mix different simulation types, such as glare and illuminance, at the same time.

4. PROPOSED ADD-ON'S FRAMEWORK

A new Add-on's framework is proposed aiming address the mentioned four points in order to enable automatic daylight simulation for kinetic facades by determining the best kinetic shading mechanism for achieving optimal daylight in areas at various angles and times, as well as glare and illuminance simulation. The proposed Add-on structure is illustrated in the following graph, that includes the Add-on's steps and codes.

As illustrated in Figures 1 and 2, the proposed Add-on is split into three primary phases: first, input phase (fixed and variable parameters), second, optimization phase, and third, output phase.

4.1. Input Phase

To start any simulation, inputs are needed. In the proposed Add-on, there are fixed and variables inputs. Each one is divided to various sub-inputs as follows.

Three types of fixed inputs parameters are supposed to exit, which are:

- Environmental parameters: containing the orientation of the building and the weather file that is required to collect hourly solar radiation for a specific area.
- Architectural space parameters: containing all simulated space data, such as room size, dimensions, proportion, area, opening ration and opening placement.
- Kinetic parameters: containing the related data to kinetic units, such as speed, geometry and weight

Furthermore, the variable inputs are split into two categories:

- Kinetic parameters: these include rotation, open and shut, and other kinetic shading motion parameters.
- Time/date parameters: simulation period includes hours, days, and months throughout the year.

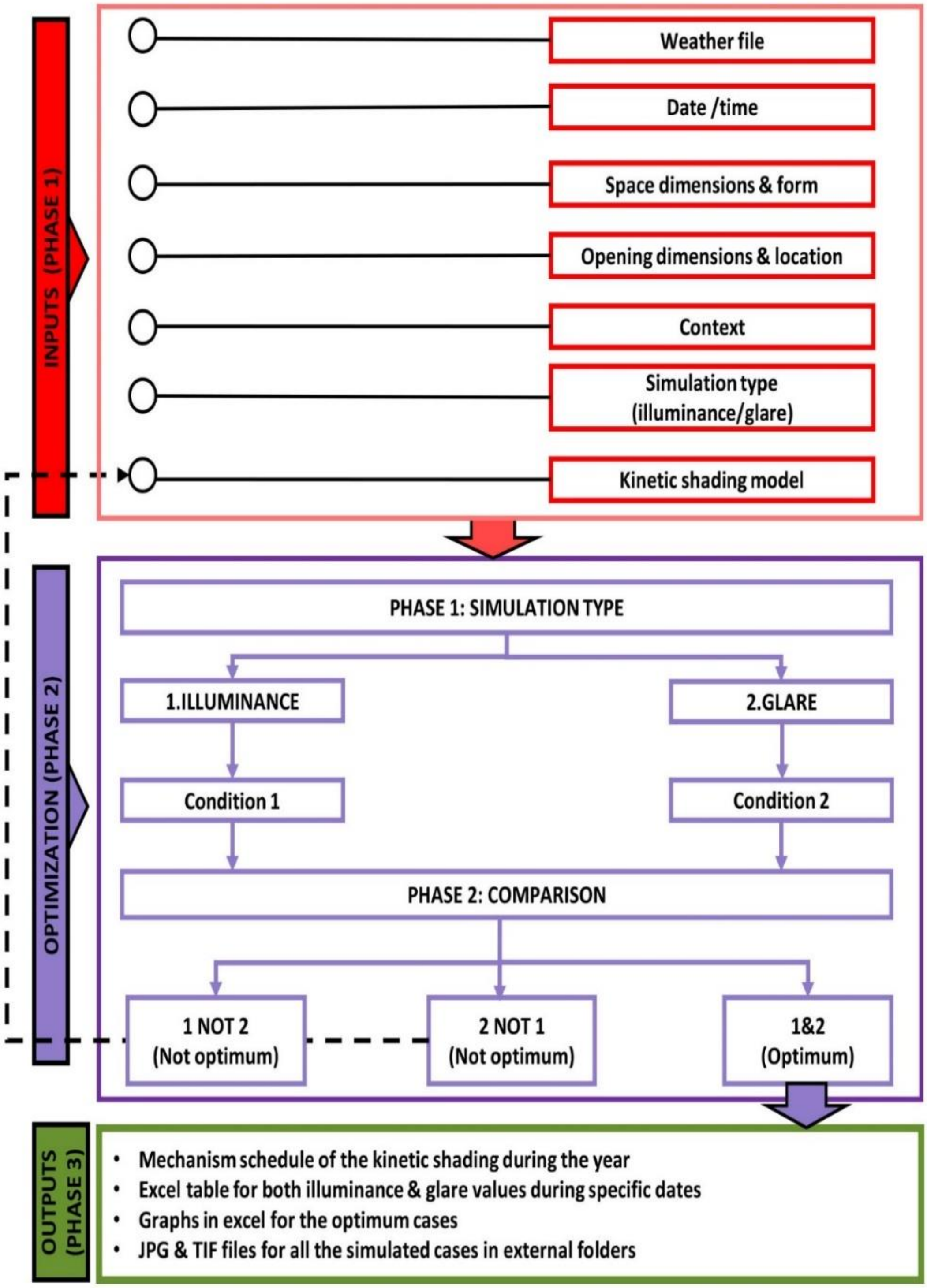


Fig.1: Diagrams shows the general Add-on framework divided into three main phases

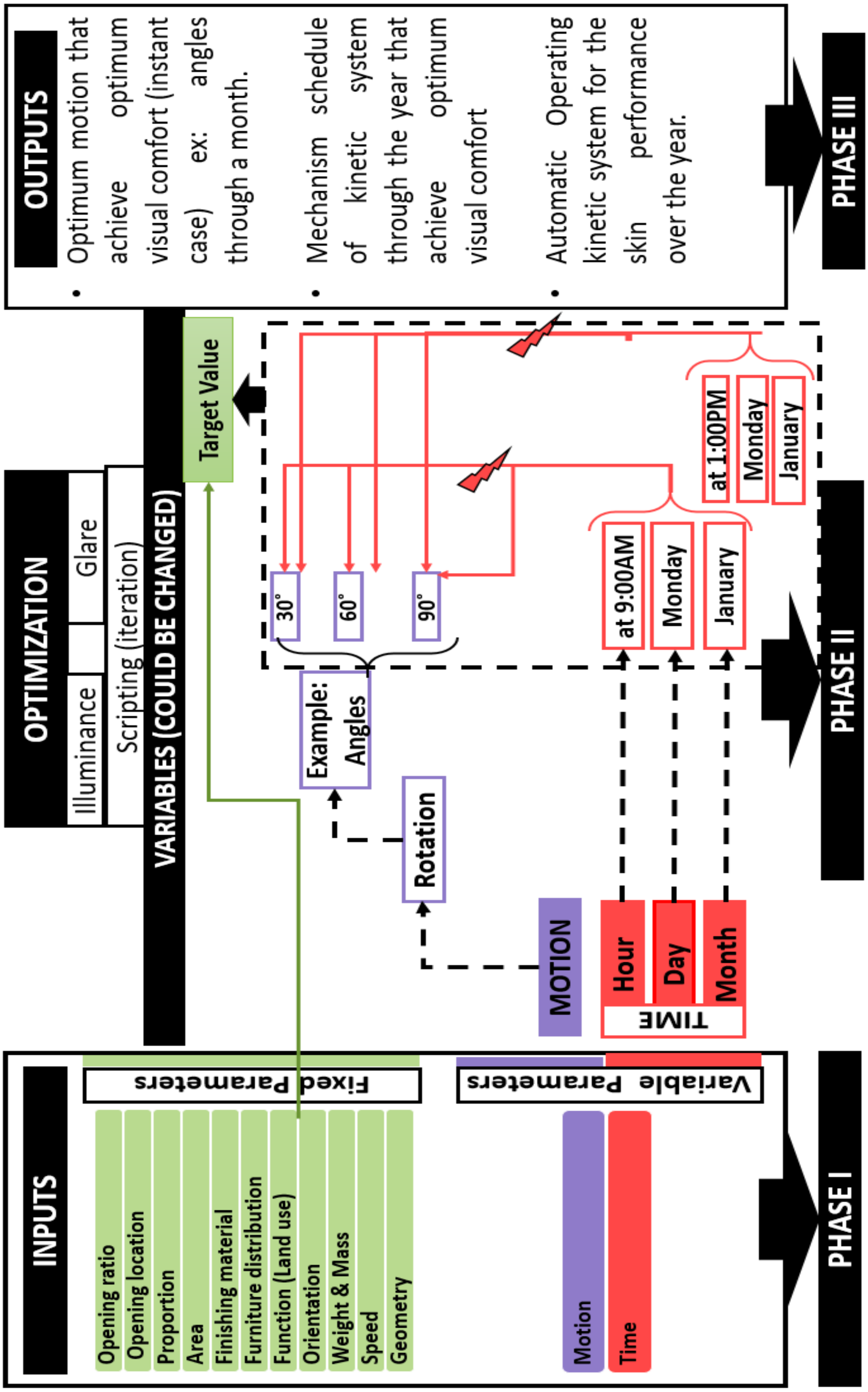


Fig.2: Diagram that shows the detailed Add-on framework including inputs, operation and outputs

4.2. Optimization Phase

The optimization phase, which includes both illuminance and glare simulations, is illustrated in Figure 3. Each operates differently in order to achieve the best results over a period of time. The automation date/timing range was built using an automated script, so the user does not have to constantly update the simulation time and date. The optimization goes via an automated optimization loop towards two primary checking gates to achieve optimum visual comfort and daylight. The first gate verifies that the illuminance values are within the intended range, while the second verifies that the glare inside the DGP range is appropriate. The findings of both gates will then be compared, and the final optimization results will be checked. The outputs will be displayed in the next phase if the results were optimal, but if they were not, the user must modify the kinetic shading models' variables and simulate again.

4.3. OUTPUT PHASE

Following the optimization process, the output should look like this:

- Values for both glare and illuminance at the same time in Grasshopper 3D.
- Illuminance and glare values on an Excel sheet and table.
- Kinetic shading mechanism schedule in an excel table for each of the optimum scenarios' individual simulation time and date.
- Excel graphs for the best kinetic shading mechanism for visual comfort and optimal daylight at a given moment.
- Identifying the best scenarios for each simulation (in text).
- All simulated cases in defined scenarios are saved as TIF and JPG files in external archives.

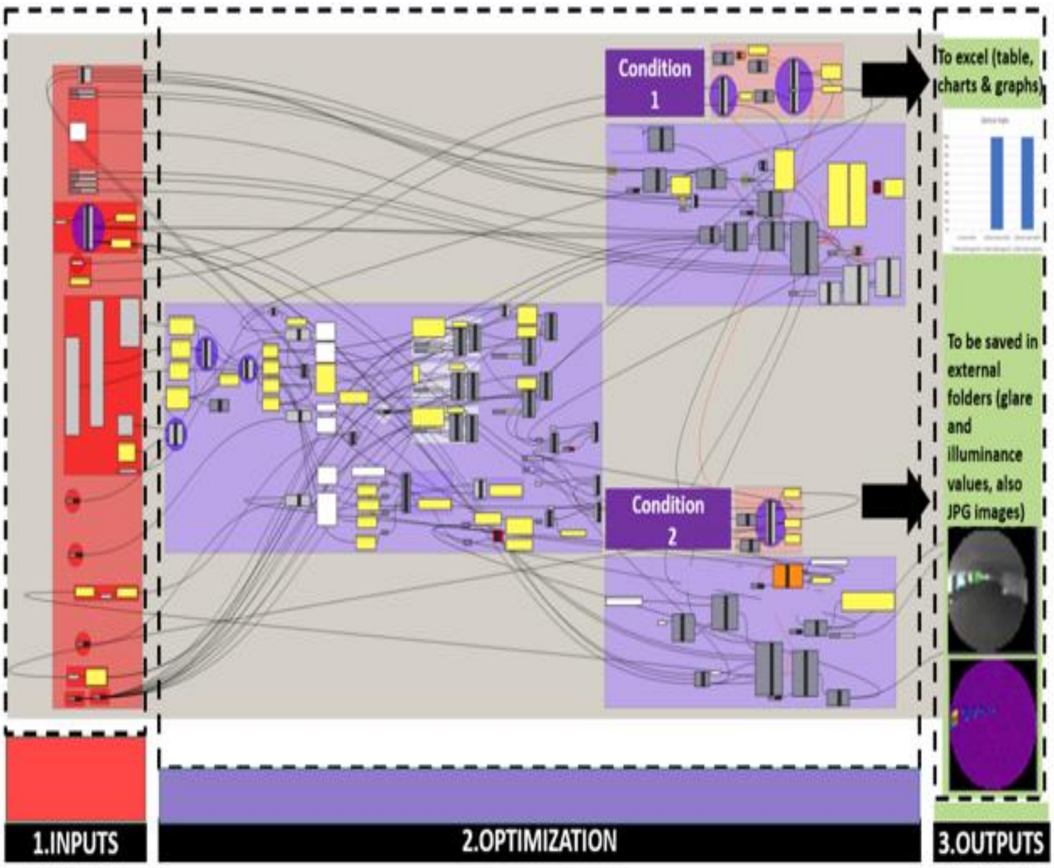


Fig.3: Add-on plugin phases using ladybug and honeybee in Grasshopper for Rhino

Different programming languages can be used to construct a script; python is the programming language used in this research. To construct this add-on, various scripts are written inside the Grasshopper3D software environment, each script serving a specific role, as shown in Figure 3. The following is a list of the seven written scripts:

1. Script 1 contains simulation type, which seeks to select the simulation type by including a check list for several types of simulations to run, such as illuminance, glare simulation, and both will perform the simulation, while when it is set to false, the simulation will stop
2. Script 2 displays the angel values, which allow the user to choose the angles that will be used in the simulation. The second script's inputs are a list of angle values that can be checked or inserted by users, with the output being the selected or written angels that will be utilized in the simulation.
3. Script 3 is the animation slider value is used to calculate the value of a series of simulations run for various inputs such as angles and time. A list of months, days, hours, and angels are entered as inputs.
4. Script 4 is about date and angels, which aims to identify the required period of time and the angels' values for the simulation, including a list hours, days and month, and angels' values, which are inserted into the x, y, z, and v variables inputs, as well as the animation slider value, which is implanted into the u variable input for activating the simulation.
5. Script 5 displays the illuminance target value, which is used to specify the illuminance value required in a certain area.
6. Script 6 is the illuminance condition, which is the procedure for determining whether or not the amount of illuminance is sufficient.
7. Script 7 offers optimization conditions that aid in determining the sequence in which the simulation logic should go in order to achieve the best kinetic shadings situation in a given amount of time. The condition for both illuminance and glare to provide optimum visual comfort in a certain function and location is included in this script.

5. ADD-ON GRAPHICAL USER INTERFACE (GUI)

As illustrated in Figures 4 and 5, all the components utilized in this Add-on have been clustered and combined to make the GUI more user-friendly. As a result, nine components have been replaced by 51 components as a final GUI:

Component 1: simulation inputs is used to collect all simulation inputs, such as the kinetic shading system, geometrical space components, weather file, and simulation period.

Component 2: illuminance simulation, which is used to simulate illuminance.

Component 3: glare simulation, which is used to carry out the glare simulation.

Component 4: simulation type, which is used to turn on or off the simulation.

Component 5: list value for choosing between illuminance, glare, or both types of simulation.

Component 6: function type, which allows you to choose between different space functions such as library, classroom, and so on.

Component 7: optimization tags, which are used to define the best results by demonstrating simulation values.

Component 8: create cases for automating the simulation for a variety of kinetic situations in a row.

External excel sheet data (component 9) is used to keep a record of all simulation results.

DOI: 10.54729/2789-8547.1208

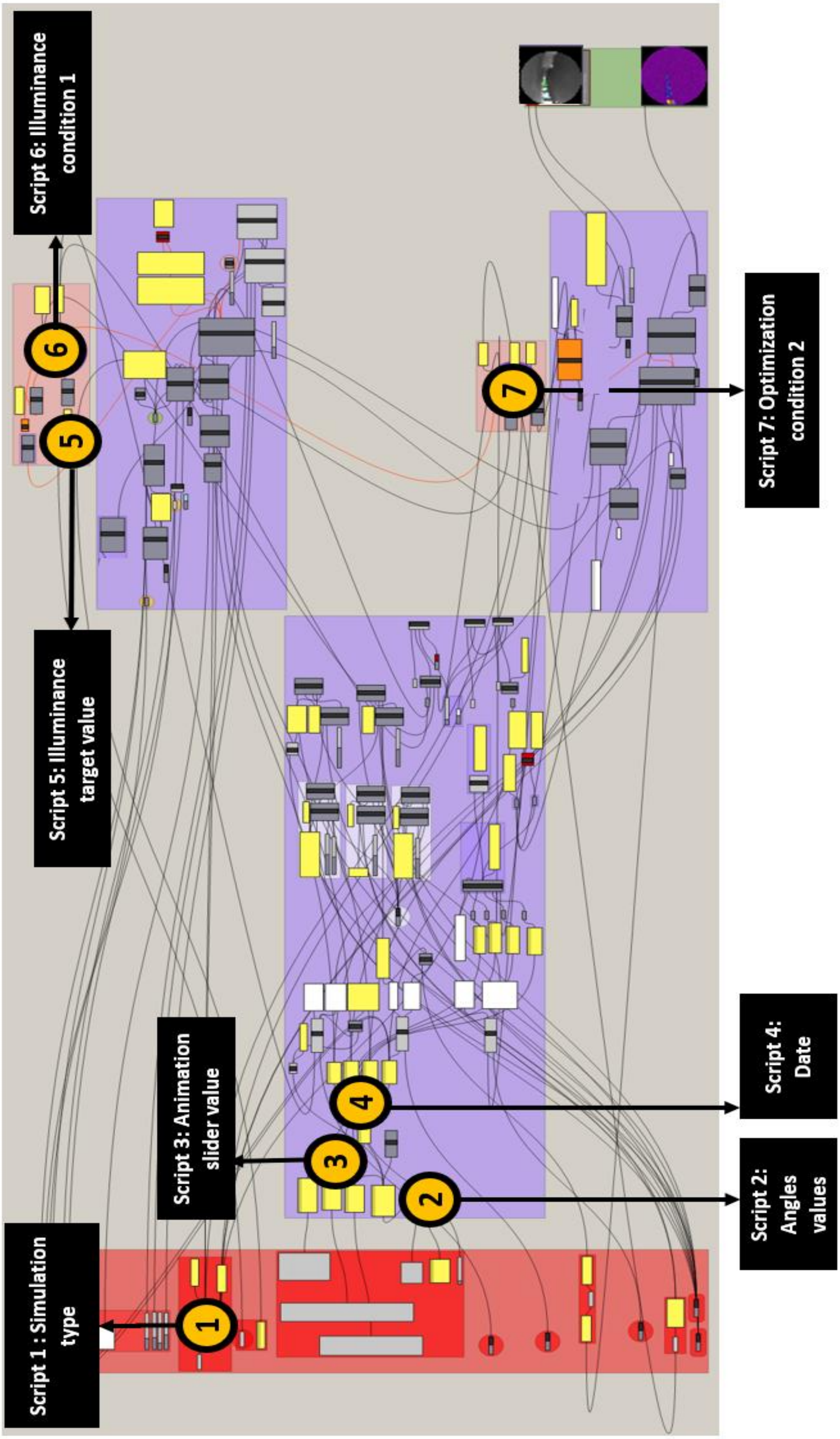


Fig.4: Six scripts created in the proposed add-on

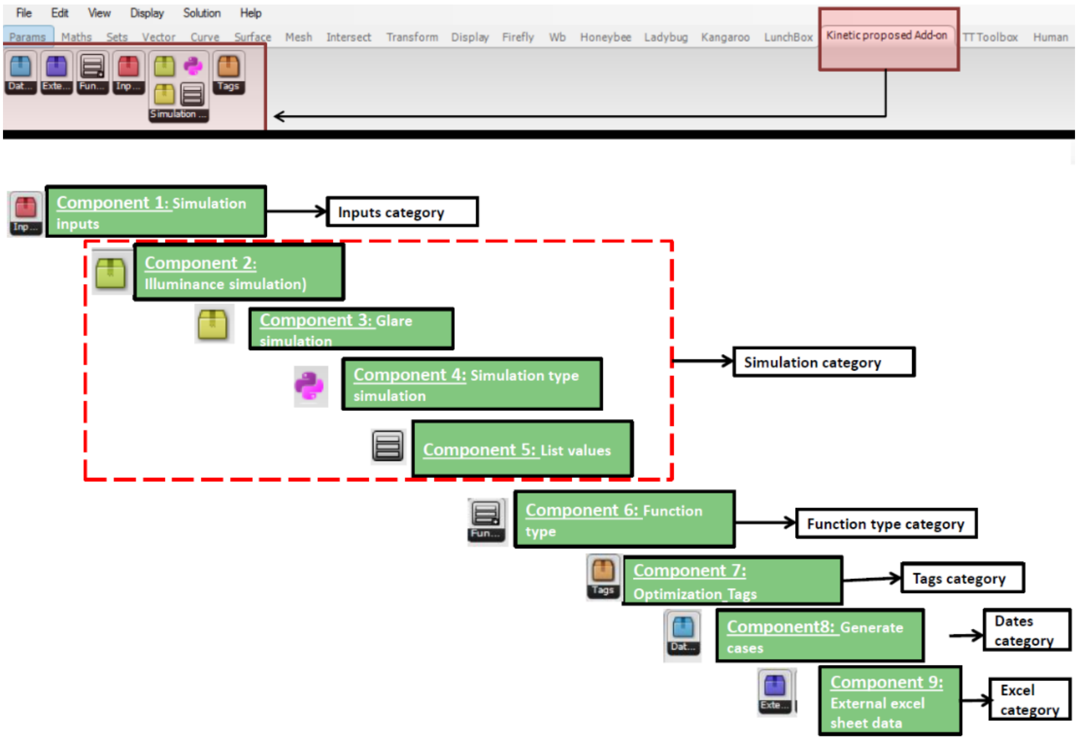


Fig.5: Add-on components through GUI

5.1. Proposed Add-On Application

Many people spend the majority of their time in educational settings. Natural lighting is vital for students' wellbeing and mental health; hence it should be considered while increasing their visual task performance. However, it may be unsuitable in areas where glare is noticeable. As a result, there is a requirement for users, particularly students, to have a suitable amount of natural daylight while practicing their visual skills in a pleasant and relaxing atmosphere (Bakri, 2014).

In university libraries, daylighting has a significant impact on users' perceptions, satisfaction, and behavior. Libraries are regarded an important element of university, where there is a strong emphasis on self-learning, with the library playing a vital role in providing students with access to information, documentation, and data references, among other things. Furthermore, the library's architecture and daylighting may increase usage and encourage students to use it during their free time rather than only during exams.

An application is need it to be applied on educational space to verify and test the proposed Add-on. Thus, the selected space is the library of BAU University, located in Tripoli, North Lebanon, as shown in Figure 6 and 7.

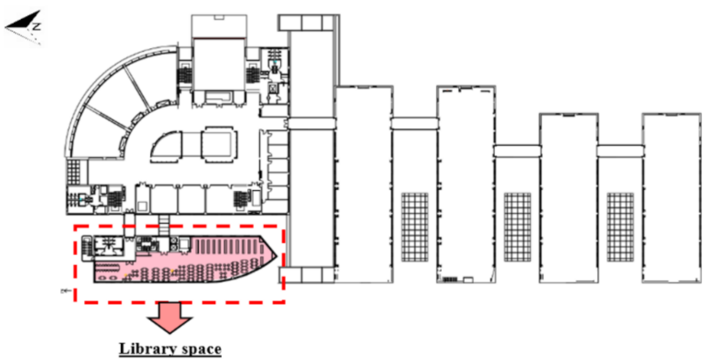


Fig.6: Library location in BAU University

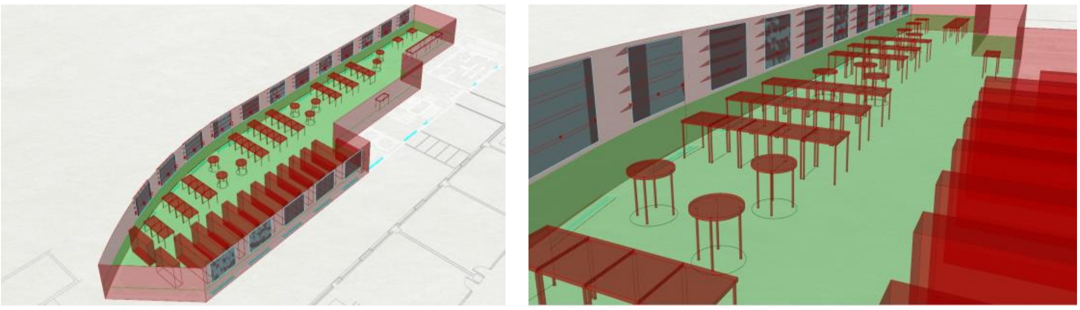
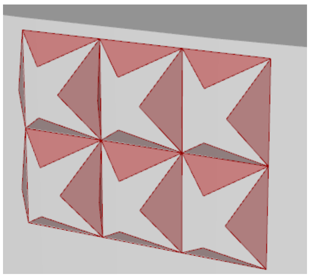
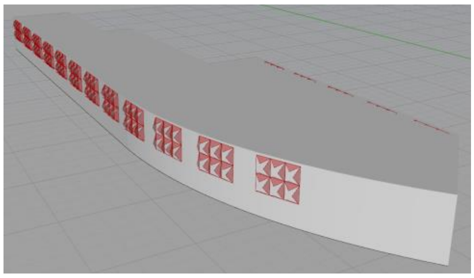


Fig.7: Table location (task area) inside the library

A kinetic shading system was implemented as a simulation on the library's windows using Grasshopper for Rhino software, as indicated in table 1. The simulation method begins by inserting variables and fixed inputs, such as kinetic units' geometry, mechanism, space, and opening dimensions, and so on, in order to have a better control over the shade. The goal illuminance value is automatically adjusted to 500 lux after selecting the function for the examined space, in our case the library. Then choosing dates, such as months, days, and hours. Additionally, choosing the angles of the mechanism that will change during the kinetic shading simulation. As a result, rather than simulating each case individually, all cases at various dates and angles will be simulated automatically. After all of the inputs have been entered, the optimization process will begin with illuminance and glare simulations. Under an overcast sky, illuminance and glare must be calculated. A 0.5*0.5m grid is used, and a working space of 0.85m is supplied.

Table 1 The three kinetic shading types used in the research

Kinetic shading Case number	Kinetic shading units	Kinetic shading on library's windows
Case 3 **Square**		

5.2. Evaluating the Suggested Add-On's Performance

The proposed Add-on could be utilized for the entire year, 12 months, but three months were chosen to test its performance in different seasons and reduce simulation time. The three months chosen are June, which has the longest day of the year, known as Summer Solstice, December, which has the shortest day of the year, known as Winter Solstice, and March, which has day and night lengths that are equal, known as Vernal Equinox, and is very similar to September, which is known as Autumnal Equinox. Three days were chosen from each month, 20, 21, and 22, as they reflect daylight length critical points (weather.gov, 2020). Case 3: The Add-on was used at three different times during the working day. Using case 3, the Add-on was applied to three different angles (30, 45, and 60) during working hours (10:00AM, 13:00PM, and 16:00PM), resulting in DPG and illuminance values, as shown in Figures 8 and 9. Illuminance and DPG values are automatically calculated and saved externally for each example during the simulation process, both numerically and graphically.

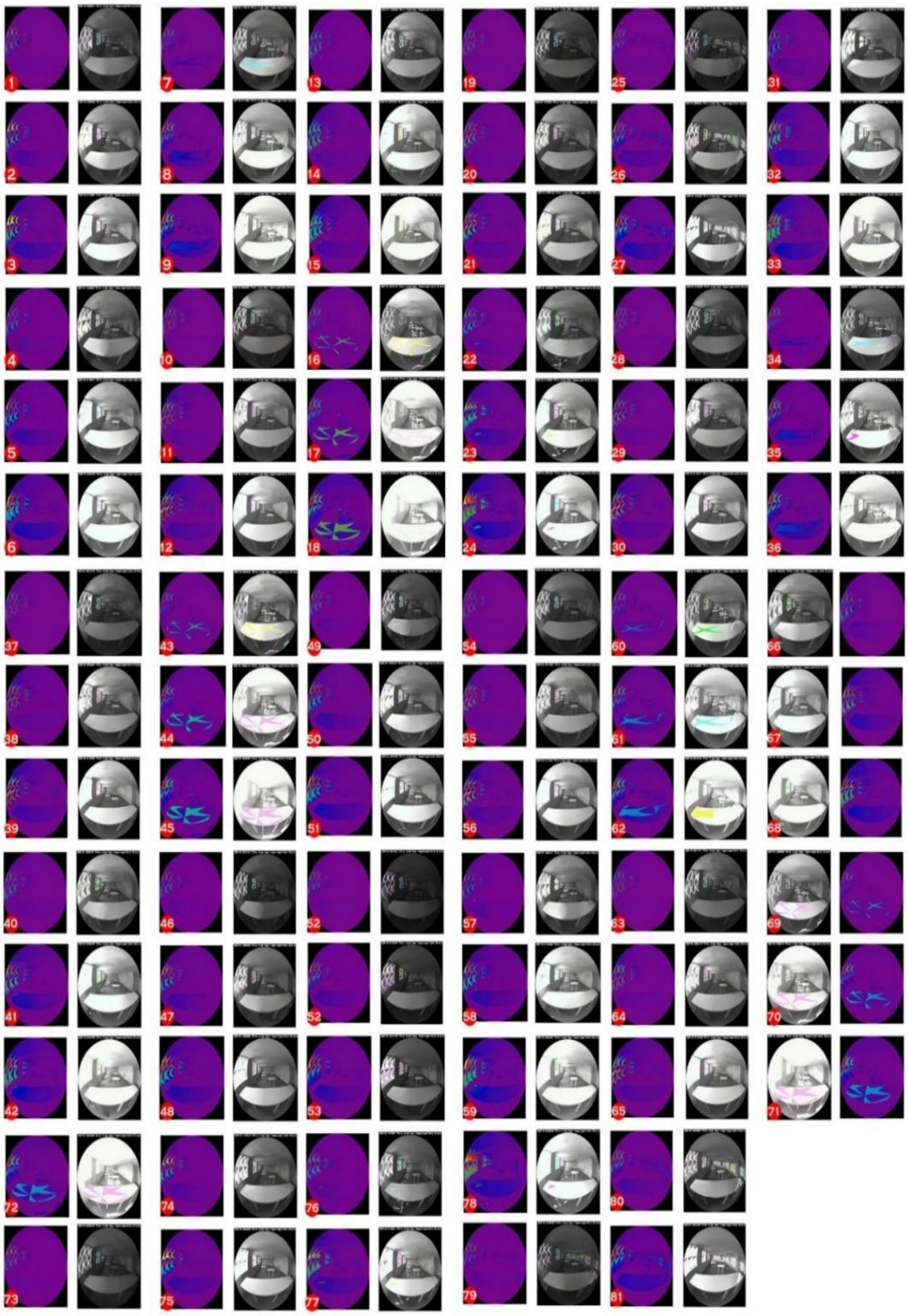


Fig.8: 81 DPG results values after doing glare simulation using the proposed Add-on at three different months, time, and angles for case 3

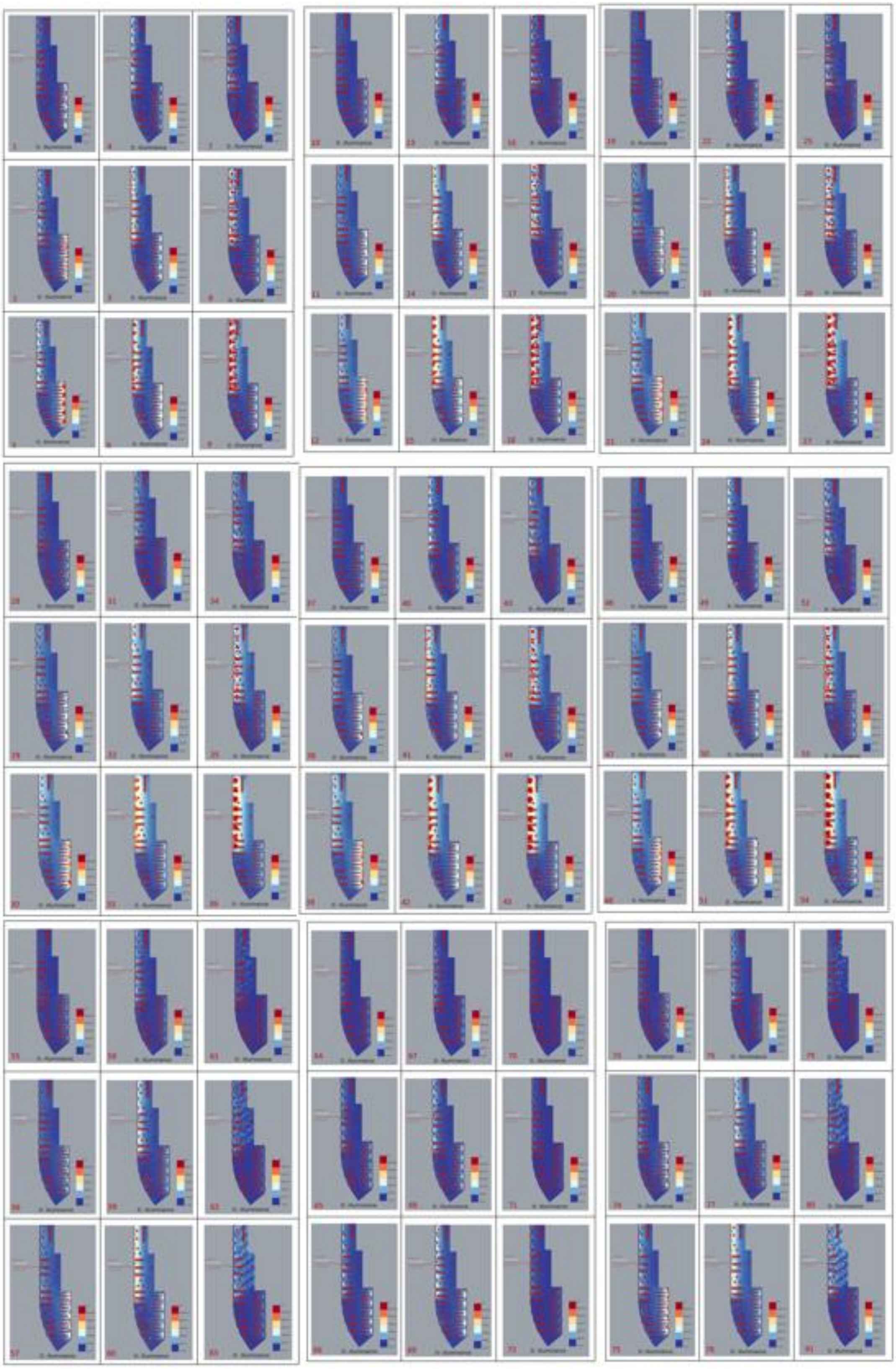


Fig.9: 81 Illuminance values as results after doing glare simulation using the proposed Add-on at three different months, time and angles for case 3

5.3. Results After Add-On Application

This application has emphasized the optimum glare and illuminance conditions. This allows the user to check angles in terms of efficiency and visual comfort not only in the graphical interface, but also quantitatively in an external excel sheet for all values, highlighting the best scenarios, as shown in table 2. The user can now specify the ideal mechanism of the kinetic units based on these optimum outcomes at various simulated dates.

Table 2: shows excel sheet as output after glare and illuminance simulation during three months, using the proposed Add-on and highlighting the optimum results

	Date	visiual comfort results	glare (DGP)	Illuminance value(LUX)	Optimum Angles
1	20 MAR 10:00at angle:30.	no visual comfort	0.099251	156	0
2	20 MAR 10:00at angle:45.	no visual comfort	0.206883	272	0
3	20 MAR 10:00at angle:60.	no visual comfort	0.215862	406	0
4	20 MAR 13:00at angle:30.	no visual comfort	0.154906	160	0
5	20 MAR 13:00at angle:45.	no visual comfort	0.210017	296	0
6	20 MAR 13:00at angle:60.	no visual comfort	0.224101	424	0
7	20 MAR 16:00at angle:30.	no visual comfort	0.176012	146	0
8	20 MAR 16:00at angle:45.	no visual comfort	0.211465	326	0
9	20 MAR 16:00at angle:6	Optimum visual comfort	0.230538	558	1
10	21 MAR 10:00at angle:30.	no visual comfort	0.079326	270	0
11	21 MAR 10:00at angle:45.	no visual comfort	0.204766	391	0
12	21 MAR 10:00at angle:6	Optimum visual comfort	0.215511	549	1
13	21 MAR 13:00at angle:30.	no visual comfort	0.185508	279	0
14	21 MAR 13:00at angle:45.	no visual comfort	0.217262	452	0
15	21 MAR 13:00at angle:6	Optimum visual comfort	0.238024	654	1
16	21 MAR 16:00at angle:30.	no visual comfort	0.186698	162	0
17	21 MAR 16:00at angle:45.	no visual comfort	0.212512	340	0
18	21 MAR 16:00at angle:6	Optimum visual comfort	0.230821	586	1
19	22 MAR 10:00at angle:30.	no visual comfort	0.087958	322	0
20	22 MAR 10:00at angle:45.	no visual comfort	0.20728	378	0
21	22 MAR 10:00at angle:6	Optimum visual comfort	0.217165	554	1
22	22 MAR 13:00at angle:30.	no visual comfort	0.180517	218	0
23	22 MAR 13:00at angle:45.	no visual comfort	0.214938	379	0
24	22 MAR 13:00at angle:6	Optimum visual comfort	0.233297	558	1
25	22 MAR 16:00at angle:30.	no visual comfort	0.219805	239	0
26	22 MAR 16:00at angle:4	Optimum visual comfort	0.239964	517	1
27	22 MAR 16:00at angle:6	Optimum visual comfort	0.257214	909	1
28	20 JUN 10:00at angle:30.	no visual comfort	0.088343	351	0
29	20 JUN 10:00at angle:45.	no visual comfort	0.205419	464	0
30	20 JUN 10:00at angle:60	Optimum visual comfort	0.215124	785	1
31	20 JUN 13:00at angle:30.	no visual comfort	0.184939	226	0
32	20 JUN 13:00at angle:45.	no visual comfort	0.22013	442	0
33	20 JUN 13:00at angle:60	Optimum visual comfort	0.240098	722	1
34	20 JUN 16:00at angle:30.	no visual comfort	0.273715	383	0

DOI: 10.54729/2789-8547.1208

35	20 JUN 16:00at angle:45	Optimum visual comfort	0.311305	955	1
36	20 JUN 16:00at angle:60	Optimum visual comfort	0.37045	1510	1
37	21 JUN 10:00at angle:30.	no visual comfort	0.087278	329	0
38	21 JUN 10:00at angle:45.	no visual comfort	0.205407	457	0
39	21 JUN 10:00at angle:60	Optimum visual comfort	0.215283	759	1
40	21 JUN 13:00at angle:30.	no visual comfort	0.192676	245	0
41	21 JUN 13:00at angle:45.	no visual comfort	0.220412	449	0
42	21 JUN 13:00at angle:60	Optimum visual comfort	0.241788	674	1
43	21 JUN 16:00at angle:30.	no visual comfort	0.264555	361	0
44	21 JUN 16:00at angle:45	Optimum visual comfort	0.299515	871	1
45	21 JUN 16:00at angle:60	Optimum visual comfort	0.355032	1371	1
46	22 JUN 10:00at angle:30.	no visual comfort	0.097177	339	0
47	22 JUN 10:00at angle:45.	no visual comfort	0.208715	466	0
48	22 JUN 10:00at angle:60	Optimum visual comfort	0.21875	794	1
49	22 JUN 13:00at angle:30.	no visual comfort	0.194552	249	0
50	22 JUN 13:00at angle:45.	no visual comfort	0.221116	456	0
51	22 JUN 13:00at angle:60	Optimum visual comfort	0.241366	694	1
52	22 JUN 16:00at angle:30.	no visual comfort	0.256093	305	0
53	22 JUN 16:00at angle:45	Optimum visual comfort	0.288675	770	1
54	22 JUN 16:00at angle:60	Optimum visual comfort	0.340368	1225	1
55	20 DEC 10:00at angle:30.	no visual comfort	0.041554	117	0
56	20 DEC 10:00at angle:45.	no visual comfort	0.177024	227	0
57	20 DEC 10:00at angle:60.	no visual comfort	0.206619	342	0
58	20 DEC 13:00at angle:30.	no visual comfort	0.159032	132	0
59	20 DEC 13:00at angle:45.	no visual comfort	0.210389	248	0
60	20 DEC 13:00at angle:60.	no visual comfort	0.226797	367	0
61	20 DEC 16:00at angle:30.	no visual comfort	0.015288	57	0
62	20 DEC 16:00at angle:45.	no visual comfort	0.083954	110	0
63	20 DEC 16:00at angle:60.	no visual comfort	0.174284	169	0
64	21 DEC 10:00at angle:30.	no visual comfort	0.023141	54	0
65	21 DEC 10:00at angle:45.	no visual comfort	0.120648	103	0
66	21 DEC 10:00at angle:60.	no visual comfort	0.18909	153	0
67	21 DEC 13:00at angle:30.	no visual comfort	0.056932	80	0
68	21 DEC 13:00at angle:45.	no visual comfort	0.192275	156	0
69	21 DEC 13:00at angle:60.	no visual comfort	0.205766	235	0
70	21 DEC 16:00at angle:30.	no visual comfort	0.007302	20	0
71	21 DEC 16:00at angle:45.	no visual comfort	0.018137	40	0
72	21 DEC 16:00at angle:60.	no visual comfort	0.047178	61	0
73	22 DEC 10:00at angle:30.	no visual comfort	0.037619	97	0
74	22 DEC 10:00at angle:45.	no visual comfort	0.178375	182	0
75	22 DEC 10:00at angle:60.	no visual comfort	0.204498	281	0
76	22 DEC 13:00at angle:30.	no visual comfort	0.147367	121	0
77	22 DEC 13:00at angle:45.	no visual comfort	0.210027	228	0
78	22 DEC 13:00at angle:60.	no visual comfort	0.226946	344	0
79	22 DEC 16:00at angle:30.	no visual comfort	0.018633	62	0
80	22 DEC 16:00at angle:45.	no visual comfort	0.103483	124	0
81	22 DEC 16:00at angle:60.	no visual comfort	0.183106	199	0

After the simulation, the following graphs and charts are provided as graphical outputs:

- Optimum outcomes chart: in case 3, out of 81 states, there are 20 optimum states, as shown in Figure 10.
- Glare graph: this graph represents all the DPG values for the 81 states in relation to optimal values, as displayed in Figure 11.
- Illuminance graphs: that represents the illuminance values for 81 states for specified dates, times, and angles, as illustrated in Figure 12.

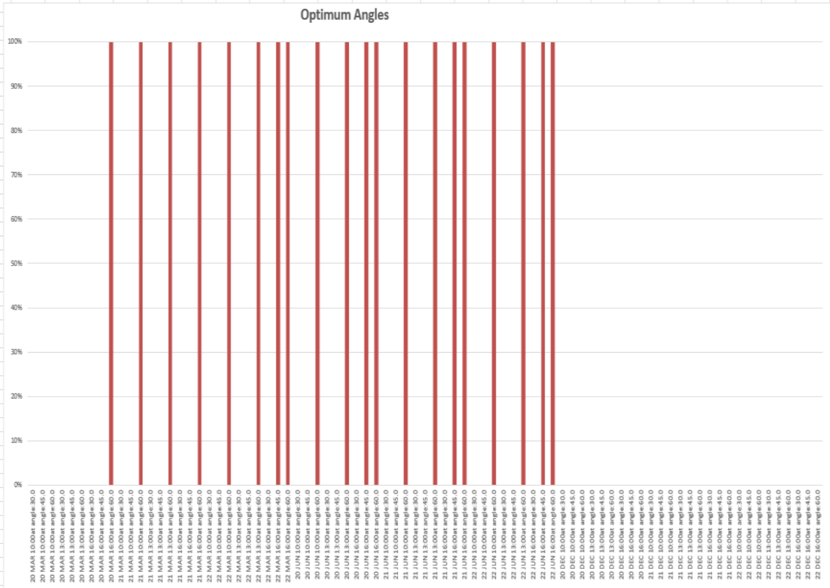


Fig.10: Chart for the optimum solutions after illuminance and glare simulations during three months, using the proposed Add-on

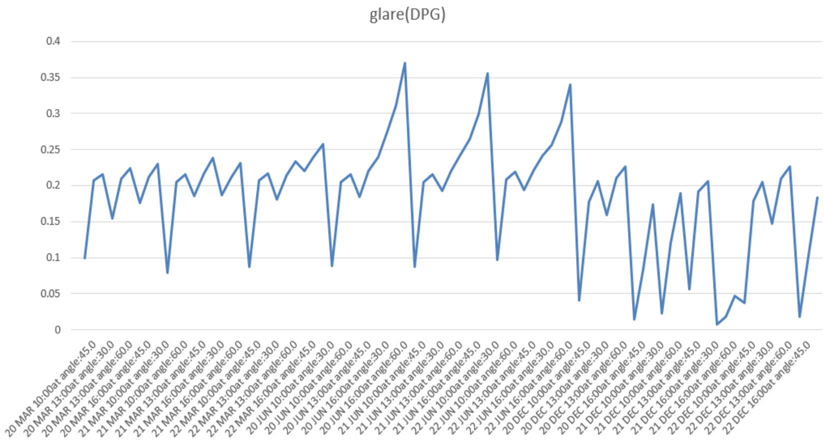


Fig.11: Chart for the glare values (DPD) after simulations during three months, using the proposed Add-*on*

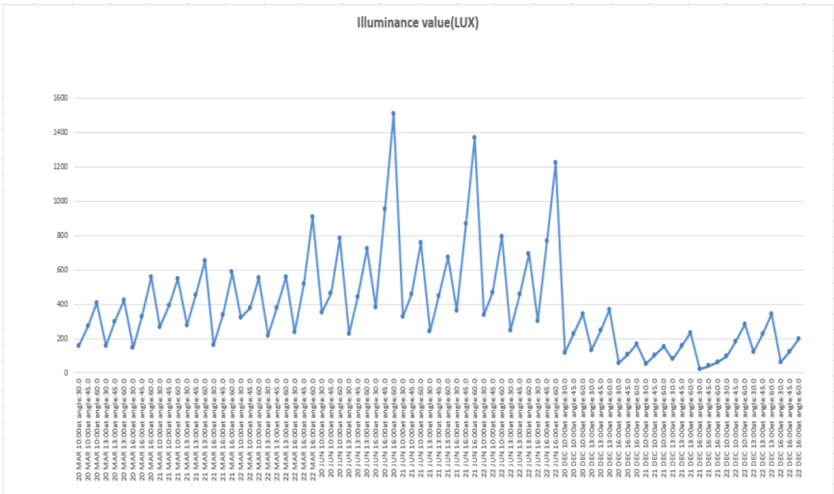


Fig.12: Chart for the illuminance values after simulations during three months, using the proposed Add-on

DOI: 10.54729/2789-8547.1208

6. CONCLUSION AND RECOMMENDATION

As a conclusion, after testing and verifying the proposed Add-on, new values are obtained when using this Add-on which are the following:

- A clear representation of optimum values of kinetic shading parameters connected to both illuminance and glare, using graphs, charts, and data sheets, where the glare range is increased from inappropriate to suitable by a percentage ranging from 51 percent to 76 percent.
- The ability to do parallel comparisons between multiple situations at the same time.
- A user-friendly Graphical User Interface (GUI) that was created for all designers from various background.
- For the proposed kinetic shading, several simulations run automatically, and both illuminance and glare simulations can run in simultaneously. With many simulations running in succession at different dates, hours, and kinetic unit mechanisms, simulation time is nearly half that of the present plugin.
- All simulation results are preserved in external files, both graphically and mathematically, so users can review any case outcomes at any time.
- The created Add-on can be generally applicable to be used not only in educational spaces, but also in various other typologies

This research has indicated the need for additional development in future study by achieving its goals to a considerable extent:

- Extend the use of the proposed Add-on to other types of functions besides educational areas.
- Expanding the Add- on to include all forms of kinetic systems, not simply the rotating mechanism.
- Expanding the Add-on to accommodate more visual comfort characteristics besides glare and illuminance.

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