Usability evaluation of a building simulation web-based design guide on potential user group

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ABSTRACT

The paper summarises the results of a usability testing exercise for a new building performance simulation based guide. The guide, presented via a web-based platform, aims to aid practitioners and policymakers during the early-design stages to achieve higher thermal and daylight performance. This study in two parts focuses on: understanding the usability of the contents of the guide; and, evaluating the design issues associated with the guide's web-platform. The results of the usability testing show that the participants generally perceived the design guide easy to use and valuable during early-stages of design. Furthermore, the participants provided suggestions on areas for possible future improvements.

INTRODUCTION

The International Energy Agency (IEA) estimates that, of the total housing stock that would exist in India by 2030, only one-fourth has been built as of 2015 with the rest yet to be constructed (IEA, 2015). This is in contrast to developed continents such as Europe and North America. The energy use in the residential building sector in India is expected to undergo a drastic change with an anticipated rise of about 65% to 75% of 2005 levels by 2050 (van Ruijven et al., 2011). Thus, regulating the performance of buildings becomes an increasingly important consideration.

In India, the construction of buildings is governed by building codes and regulations enacted by governmental departments at national and state levels. The national level building codes and rating systems like the National Building Code of India (NBC), Energy Conservation Building Code of India (ECBC), Green Rating for Integrated Habitat Assessment (GRIHA) etc. are non-mandatory and ineffective at state and local levels (Chandel et al., 2016). The State Government ultimately decides on all matters concerning land and its development, hence any proposed reform of existing building regulations should focus on State legislation and should be tailored for the specific State's needs.

In Kerala, one of the 29 states in India, the construction of buildings is governed by Kerala Municipality Building Rule (LSGD, 2019a) and Kerala Panchayat Building Rule (LSGD, 2019b). The latest update (2019) of these building rules does not provide any measure to ensure energy efficiency in the construction of new residential buildings. Meantime, as part of the Government's vision to provide housing for all, a project titled \Livelihood Inclusion and Financial Empowerment (LIFE) mission" is being implemented. Under this project, the Government of Kerala plans to build more than 750,000 houses (Issac, 2018). The beneficiaries (i.e. the people of theState) are free to choose from among 12 proposed designs which will be used for the construction of buildings, irrespective of the location or climate. A number of previous studies (Jayapalan Nair et al.,2018, 2019) identified regions in Kerala with different climate characteristics and suggested that designs should be tailored for the different climate zones.

Currently there are no guidelines provided in the State's building codes to ensure energy efficiency in the construction of new residential buildings. Thus, a new building performance simulation (BPS) based design guide was developed to remedy this short coming. The guide aims to assist practitioners and policymakers during early-stage design to achieve higher than typical/average thermal and daylight performance. This paper is organised into three parts. The first part gives a brief description of the guide. The second part describes the methods used to assess the usability of the guide. The last part presents the results of the usability testing.

DESCRIPTION OF THE GUIDE

The guide, based on the users, preferences/constraints, provides the building performance measure (i.e. the annual energy demand and/or the Useful Daylight Illuminance values) and a corresponding list of sensitive parameters (and their values). The guide is presented via a web-based platform. Users can navigate the website by going through six main steps, in which they are asked to select design parameters based on either site constraints or design choices.

The Home (welcome) page of the website gives an overview of these six steps and provides video tutorials. The six steps are as follows:

Step 1: Select the location

In the first step, the user is asked to select the location of interest. The selection of the location informs the

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user of the determined the climate zone and suggests building designs tailored for those climatic conditions.

Step 2: Select the building context

The second step is to select the building context. Here the user is asked to select whether the building is planned to be constructed in an open low-rise (rural), dense low-rise (urban) or dense high-rise context.

Step 3: Select the building base form

The designs provided in this guide are for three base-forms (see Figure 1) and in the third step, the user is asked to select one of these.

Step 4: Select the orientation of the building

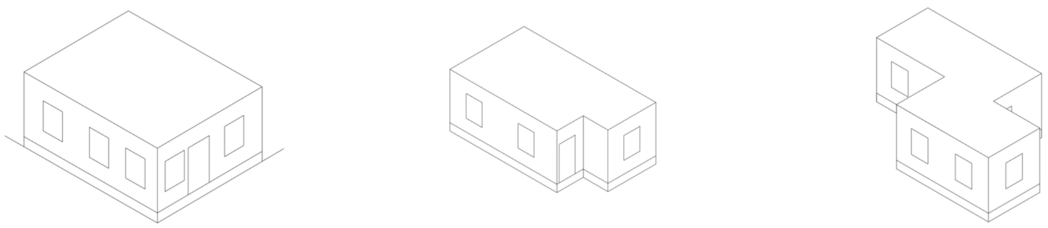
The fourth step is to select the orientation of the building. The main entrance door is used as the reference to define the building's orientation.

Step 5: Select the building's design priority

Once the orientation is selected, the next step is to select the building's design priority which could be - high thermal and/or daylight performance. The thermal and daylight performance of the designs were assessed based on the annual energy demand for heating and/or cooling and the Useful Daylight Illuminance metrics (Mardaljevic, 2015) respectively.

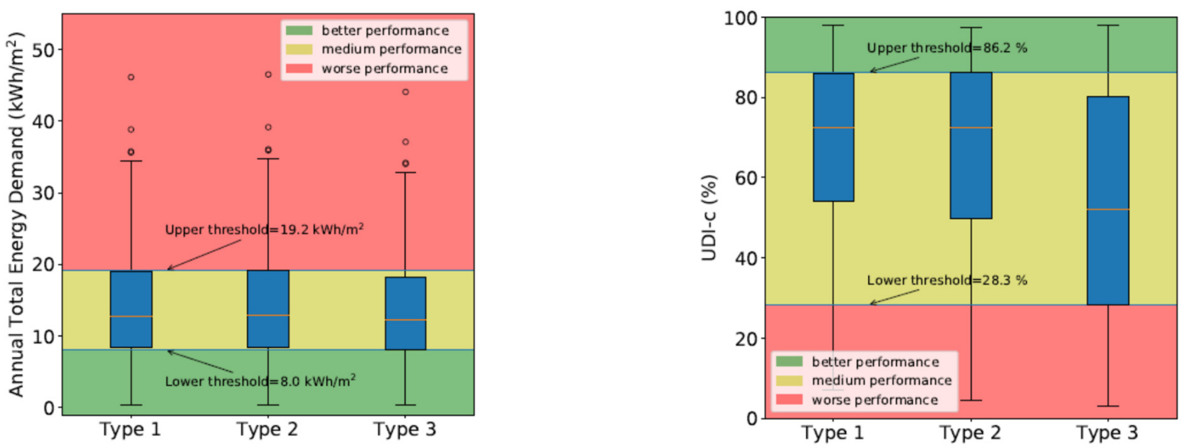
The performance of the designs were categorised into better, medium and worse based on the results of an Uncertainty Analysis (UA) performed using a Latin Hypercube sampling procedure (Hopfe and Hensen, 2011). For the UA, a number of design parameters including Window-Wall Ratio (WWR) for different facades, U-values and optical properties of the main building elements were considered (Jayapalan Nair et al., 2020). A total of 750 design variations, 250 for each of the different building base-forms were investigated.

Figure 2 shows the results of the UA for thermal and daylight performance for the three building base forms, when oriented towards the South direction and located in the city of Thiruvananthapuram. In Figure 2a and 2b, the box and whisker plots show the 25 and 75 percentile values of annual energy demand (kWh/m^2) and Useful Daylight Illuminance-combined metric (UDI-c), respectively. These values were used to define performance thresholds. The annual energy demand value corresponding to the lowest 25th percentile from among the three base-forms was defined as the lower energy threshold and that corresponding to the 75 percentile as upper energy threshold. The designs having an annual energy de-



(a) Type 1 (b) Type 2 (c) Type 3

Figure 1: The three base-form building types presented in the guide.



(a) Thermal performance *(b) Daylight performance*

Figure 2: Results of Uncertainty Analysis for the different base-form building types when located in the city - Thiruvananthapuram. The upper and lower threshold values were used to categorise designs into better, medium and worse performance.

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mand below the lower threshold were categorised as showing better thermal performance. The designs exhibiting an annual energy demand higher than the upper threshold were categorised as showing worse thermal performance. All other designs were categorised as showing medium thermal performance. The same applies to the categorisation of daylight performance (see Figure 2b).

To select the design priority, the user is provided with three options: thermal, daylight and combined. If thermal is selected, the user is taken to the next step where all the designs showing better thermal performance (i.e. total energy demand below the lower threshold value) are provided. The same applies for daylight and combined (better thermal and daylight) options.

Step 6: Select the building's design parameters

The selection of the design priority leads the user to the design selection page where design variations are presented using a parallel coordinates plot. The parallel coordinates plot is a type of data visualisation method that is ideal for comparing a number of variables (e.g. WWR, U-values, etc.) and outcomes (e.g. thermal and daylight) based on a particular design (Figure 3). Each variable (design parameter) is given its own vertical axis. A Sensitivity Analysis (SA) - based on the Morris method (Saltelli et al., 2004) and performed on the same design parameters considered for the UA { allowed the selection and inclusion in the parallel coordinate plot of only the most sensitive parameters. Each axis is placed parallel to each other and have different scales. The values across the axes are interconnected by a series of lines. Each line represents one design option linking together the corresponding design parameters and performance results.

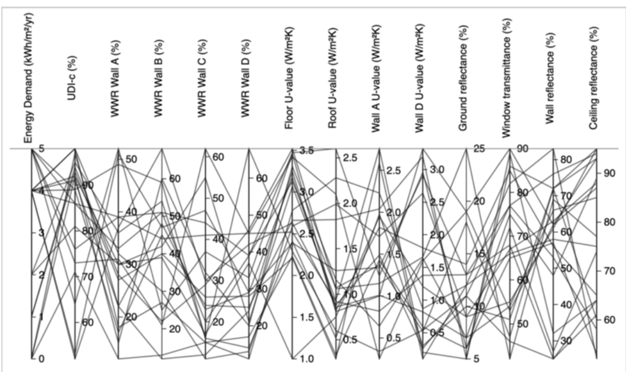
The parallel coordinates plot allows the user to filter out the design based on their preferences/goals. Figure 3 shows the parallel coordinates plot, without and with filtering applied, for a design that has a WWR for a specific wall less than 40 %, a floor U-value between 2 and 3 W/m^2 and a window transmittance value greater than 80%.

From the design selection page the users have the option to download the design report. The report provides details such as (a) executive summary, (b) brief background, (c) description of climate of the selected location, (d) details of the selected design and its thermal and daylight performance details, and (e) a technical reference section describing the simulation methods and assumptions used with details of UA and SA carried out to identify the performance thresholds and sensitive design parameters.

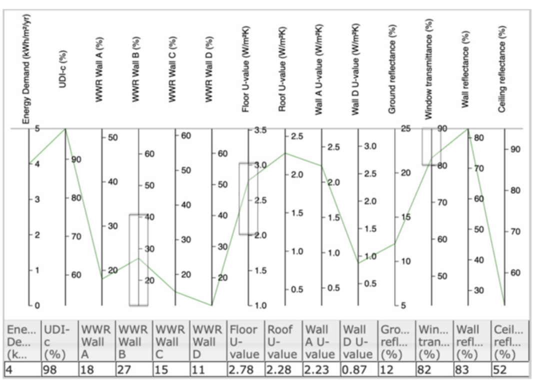
The design guidelines provided are based on pre-run simulations and are expected to give guidance during the early stages. This will help reduce the uncertainties related to the experience and level of expertise of designers as perceived by the wider building simulation community (Mahdavi, 2020), especially in Kerala's context where regulation does not recommend energy efficiency measures. Also, in the context where no guidelines are provided in Kerala's building codes, the threshold values for thermal and daylight performance provide benchmark targets as goals for for experienced designer/modellers.

The simulations were carried out based on certain assumptions regarding occupant behaviour and HVAC operations. The details regarding these are provided in the design report. If there are any significant differences with respect to the simulation assumptions, it is expected that the user will re-run the required simulations at the final stage of the design process to estimate the building's performance. Even then there may be a gap between the estimated (in final design stage) and the actual building performance due to uncertainties in construction, occupant behaviour and/or external boundary conditions.

Usability testing is a fundamental step in assessing the experiences of the potential user/target group and previous studies (Hopfe and Hensen, 2009) have shown that these evaluations are very important with



(a) Parallel coordinates plot - without filter.



(b) Parallel coordinates plot – with filter.

Figure 3: Screenshot of parallel coordinates plot from the website.

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BPS to ensure that such a tool will be accepted at the early design stage. This study aims to: (a) identify potential design/navigation issues that could affect the experience of using the guide's web platform and (b) understand the usability of the contents of the design guide to assist users during the early design-stages.

METHODS

The usability evaluation of the guide was divided into two parts. In the first part, the usability was assessed by carrying out a user experience testing to identify issues associated with the user interaction/navigation of the website. In the second part, the usability was assessed through an expert review to evaluate the quality of contents of the guide in providing assistance during early-stages of building design.

User experience testing of the website

The first part of the evaluation focused on assessing the usability of the website. The participants were recruited using criteria sampling method (Gray, 2018). The intended user group was architects and engineers. Thus, the same professional background was set as selection/recruitment criteria for the participants. The recruited participants all had less than five years of experience. Thus, they were categorised as early-career practitioners.

The usability was measured in accordance with the definition of usability provided in the ISO 9241 standard. The ISO standard defines usability as \the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2018). The effectiveness of the website was measured by determining the task completion/success rate and identifying the associated errors (count). The tasks for the early-career practitioners were designed to represent the most important/frequent real world scenarios that users may encounter when using the website. Task's were as follows:

Task 1: Select Thiruvananthapuram as your location;

Task 2: Chose an open low-rise building context;

Task 3: Select form Type 1;

Task 4: Change the orientation to facing true South;

Task 5: Select the design priority as thermal performance.

Task 6: Filter the designs with a WWR less than 40 %;

Task 7: Filter the designs with a floor U-value between 2 and 3 W/m^2;

Task 8: Filter the designs with a window transmit tance value greater than 80%;

Task 9: Download the executive summary of the design report.

Furthermore, the participants were asked to talk through the different steps to identify issues in the process of using the website.

The participants were asked to use their own personal computers to avoid introducing usability factors related to unfamiliar hardware. This also revealed any issues associated with monitor size, screen resolution and browser compatibility. It is normal to include completion times in any usability assessment. However, as participants accessed the website from different locations, the task completion time was affected by the varying internet connection time and hence not noted.

User satisfaction with carrying out the tasks was measured with the help of scores derived from a post-task user satisfaction questionnaire. The user satisfaction score was measured using a five-point Likert scale (0- strongly disagree, 1- disagree, 2- neither disagree nor agree, 3- agree and 4- strongly agree) (Likert, 1932). To calculate the mean satisfaction score, for positive oriented questions, the response of strongly disagree was given the minimum score of zero and the response of strongly agree was given the maximum score of four. For the negative oriented questions, the response of strongly disagree was given the maximum score of 4 and the response of strongly agree was given the minimum score of zero.

Expert review of the guide

The second part of the evaluation focused on the expert review of the contents of the guide. The semi-structured interview was used to gain greater understanding of the usability issues associated with the content of the guide. The participants were recruited using an intensity sampling method (Gray, 2018) based on their expertise. This allowed the gathering of valuable information to understand and improve the usability of the guide. Based on background and experience, the participants were categorised into two groups:

1. **Policymakers** (seven participants): Politicians, architects, engineers and building physicists who are involved in policy-making on behalf of the Government of Kerala;
2. **Experienced practitioners** (nine participants): Senior architects and engineers having more than 20 years of experience (and not involved in policy making).

The effectiveness of the guide was assessed by defining a number of tasks and measuring the task success rates. Task's 1-5 were the same as those performed for the user experience testing. For Task 6, the experts were asked to select their preferred design and download the report.

The efficiency and satisfaction was measured simultaneously by organising a semi-structured interview around a post-task user satisfaction questionnaire.

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RESULTS AND DISCUSSION

User experience testing of website

To understand the issues associated with the ease of navigation through the website, a usability testing exercise was carried out with early-career practitioners. For this, the participants were asked to navigate through the website carrying out a number of tasks. Table 1 presents the results of the exercise. Out of the nine tasks, the first five tasks were completed successfully by all the participants. Out of the 11 participants, one opted out at the sixth task, which involved filtering out a design based on a certain criteria. Thus for that participant, the remaining tasks were marked as not completed/unsuccessful. For tasks 6, 7, 8 and 9, the task success rate is 73 %. For these tasks, the participants who made an error (n=2), filtered out the wrong design. The reason reported by these participants were that they did not read the task carefully.

To further understand the user experience in using the website, the participants were asked to fill in a post task questionnaire. Figure 4 presents the user satisfaction scores of this exercise. The mean satisfaction score was 2.98 out of 4, very close to `Agree'. To identify the issues associated with the ease of navigation, the results of the user satisfaction score were analysed together with the verbal comments. The lowest score (2.64) was observed for the statement "I found it easy to select the desired design" (Figure 4). Some participants, though they had successfully completed the tasks (Tasks 6-8), mentioned that it was their first experience with parallel coordinates plot and that they were not aware of the filtering option until they watched the video provided on the webpage. The website design was revised according to these findings.

Expert review of the guide

Expert review was carried out to inform about the quality of the contents of the guide. The task (successful) completion rate for all the participants was

Table 1: Results of website usability testing exercise.

Task*	Task success rate (%)	Error description	Reason(s) expressed by participant
Task 1	100%	-	-
Task 2	100%	-	-
Task 3	100%	-	-
Task 4	100%	-	-
Task 5	100%	-	-
Task 6	73%	1. Unable to apply filter (n=1). 2. Incorrect filtering range (n=2).	1. Don't know how to apply filter (n=1). 2. Don't know how to remove filter (n=1). 3. Did not read the task carefully (n=1).
Task 7	73%	1. Discontinued at Task 6 (n=1). 2. Incorrect filtering range (n=2).	1. Don't know how to apply filter (n=1). 2. Did not read the task carefully (n=2).
Task 8	73%	1. Discontinued at Task 6 (n=1). 2. Incorrect filtering range (n=2).	1. Don't know how to apply filter (n=1). 2. Did not read the task carefully (n=2).
Task 9	73%	1. Discontinued at Task 6 (n=1). 2. Downloaded the wrong executive summary (n=1). 3. Downloaded the design report instead of executive summary (n=1).	1. Don't know how to apply filter (n=1). 2. Did not read the task carefully (n=2).

n - number of participants. * detailed description of the tasks is presented in the methods section.

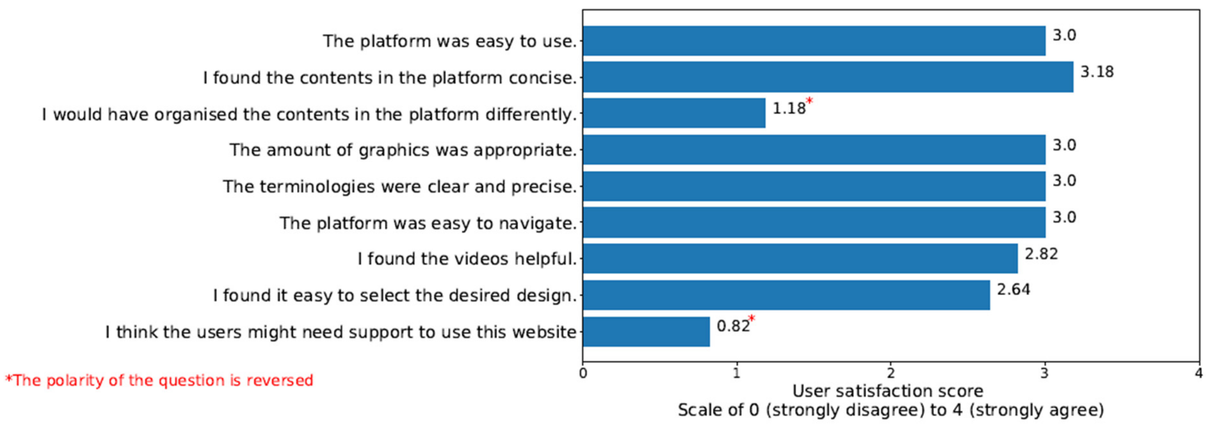

Figure 4: User satisfaction score based on usability testing for website.

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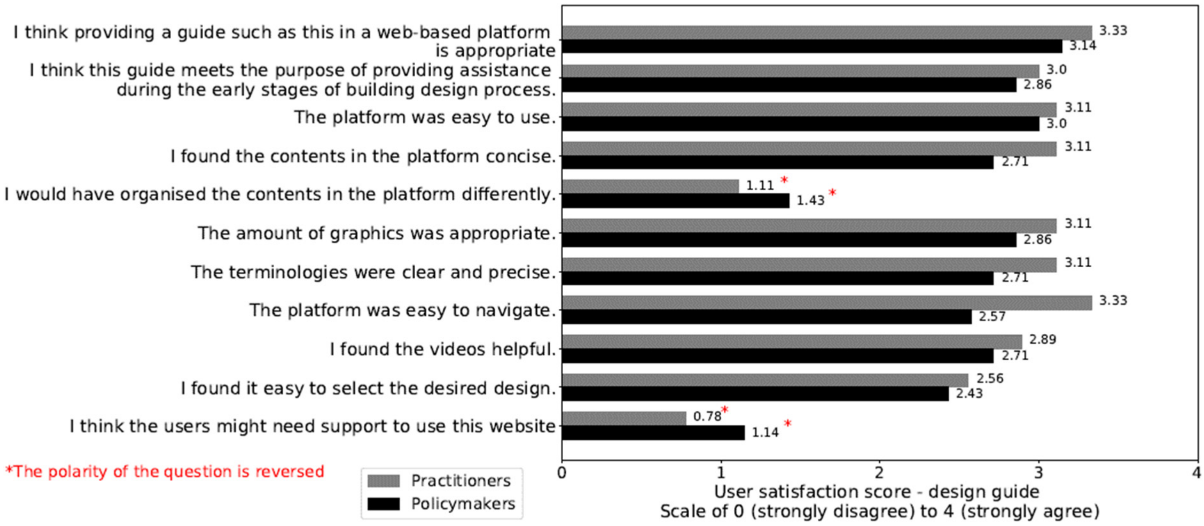

Figure 5: User satisfaction score based on expert review for guide.

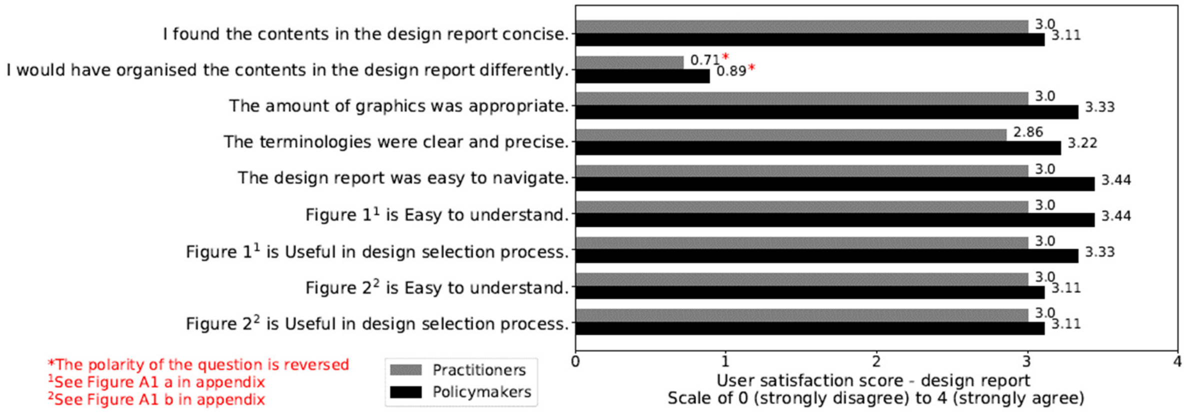

Figure 6: User satisfaction score based on expert review for report.

100 %. Figure 5 and 6 present the results of the user satisfaction questionnaire for the guide and the report, respectively. Studies have shown that in Agree-Disagree questionnaires, participants have a tendency to select the agree option disproportionately more often than disagree option and this can lead to incorrect conclusions (Krosnick and Fabrigar, 2001; Saris et al., 2010). Thus to control the acquiescence bias, the questionnaire had positive and negative oriented statements.

The mean satisfaction score for the guide was very close to three (2.91 out of 4) with the score from practitioners being 3.06 and policymakers being 2.77. The mean satisfaction score for the report was also very close to three (3.02) with the score from practitioners being 3.11 and policymakers being 3.20.

From the results, it is evident that practitioners were comparatively more satisfied with the guide than policymakers (Figure 5) whereas when it comes to user satisfaction score for the report this is reversed (Figure 6). The analysis of the verbal comments provided further information on why there was this slight difference. Table 2 summarises the major issues and recommendations reported by the participants as part of the expert review process.

From Table 2, it can be observed that the policymakers found the design report as containing too many technical details/terms, and wanted the guide to present the contents in a simpler way which would be understood by the general public. The policymakers intended to use the report to state the problem being addressed and provide clear solution and policy recommendations based on quality evidence. The technical details were not of much interest as they were not subject specialists.

The practitioners, on the other hand, were interested in the technical details but mentioned that the report was too lengthy. They found that the background information provided in the design report was unnecessary as they were more interested in the knowing the design parameters and recommendations. The practitioners intend to use the report to compare between

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Table 2: Major issues and recommendations reported by policymakers and experienced practitioners during the expert review process.

Aspects	Reported issues/ recommendations	P	EP
Guide (website)			
Visual appearance of the guide and amount of information provided.	Website contains a lot of technical details. Present the contents in a simpler way which would be understood by the general public.	2	-
	Model designs for each zone. That would make it easier for policymakers and people in administration.	2	-
	Provide details of available materials and their properties in the website.	-	2
	The parallel coordinates plot for selecting the design is confusing.	-	2
	A need to improve the visual appeal of the website.	-	2
	Provide details as to which orientation is the best?	1	-
Omitted aspects that should be incorporated later (if possible).	Provide the cost of construction for each of the designs.	2	-
	A need to consider the supply side as well.	2	-
	Provide details of electrical appliances and their ratings, retrofitting options, net-zero design options, management and maintenance policy, type of construction to be considered after a disaster (disaster-resilient buildings), factors to be considered by tenant and landlord (upfront cost and running cost), urban heat island effect.	1	-
	Provide comparisons to vernacular architecture.	-	2
	Consider human-centric designs as one of the design parameters.	-	1
Report			
Visual appearance of the guide and amount of information provided.	A need to reduce the amount of text (background information not required).	-	4
	Provide details of available materials and their properties in the report.	-	3
	Provide details from Kerala's building code in the report.	-	1
	Similar to the website, the report also contains a lot of technical details.	1	-
Omitted aspects that should be incorporated later (if possible)	Provide the cost of construction for the selected design.	1	-

P - Number of Policymakers; EP - Number of Experienced Practitioner

different design options, and select the most appropriate one. As a solution to the revealed differing preferences, a separate download option for an executive summary and a detailed design report are now provided on the redesigned website.

Though some of the other user recommendations, such as considering human centric designs as one of the design parameters and providing details of net-zero design options (considering the supply side), fall beyond the scope of this research, they are identified as useful and important areas for further research.

The provision of the guide through a web-based platform makes it convenient to update it as and when progress is made in the recommended future research areas.

CONCLUSION

The usability testing of BPS is considered important as it helps to ensure that such a tool will be accepted at the early design stage by potential user group(s).

This study conducted a usability assessment exercise to understand issues and identify areas of improvement for a building design guide that aims to assist practitioners and policymakers during the early stages of design of high performing residential buildings. The guide is presented via a web-based platform. The first part of the study focused on an expert review with policymakers and experienced practitioners to assess the quality of the contents of the guide.

The participants response was largely positive with the mean user satisfaction score being very close to 3

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(agree) on a 0-4 Likert scale.

To understand the user experience while navigating the website, a separate exercise was carried out with early-career practitioners. Results also showed an overall positive mean user satisfaction score very close to 3 (agree) for the ease of use/navigation. The usability assessment also made it possible to identify some areas for improvement of the guide. The results of both the exercises, expert review and usability testing, showed that participants generally perceived the design guide as easy to use and valuable during the early building design stages. In the context that more than 750,000 houses will be built in Kerala in the near future and currently no guidelines are provided in Kerala's building code(s) to regulate the construction of energy efficient residential buildings, it is hoped that this tool will aid the design of buildings that exhibit higher thermal and daylight performance.

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