Topic: Low / Zero Carbon Emission Buildings and Communities

The implementation of digital tools for climate adaptation planning

Evelina Keibach[1], Homeira Shayesteh[1*]

[1] Middlesex University London, Department of Design Engineering and Mathematics, Faculty of Science and Technology, Hendon Campus, London NW4 4BT, UK;
*Corresponding email: *H.Shayesteh@mdx.ac.uk*

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SUMMARY

This paper investigates the needs and expectations of both planners and clients, identifying the main barriers to the implementation of climate adaptation software tools. It also seeks to identify the main issues on software compatibility and performance efficiency. This is achieved via the analysis of process maps produced in objective experiments with different climate adaptation tools implemented in a case study project – a sustainable neighbourhood in the city of Ulm, Germany. The ISO 25010 framework is implemented to investigate the advantages and disadvantages of these tools, including: functional suitability, information quality, reliability, performance efficiency, usability, and compatibility. The results show that current climate adaptation software tools are faced with some limitations, including a long simulation process, low interoperability with other planning software tools, and an inefficient implementation process.

INTRODUCTION

Climate change is threatening societies and economies, and is forcing landscape architects to take action while planning resilient cities. According to the European Union [1], the economic impact of climate events amounted to €95 billion in losses between 2002 and 2012. Therefore, planners are searching for solutions to enable them to adapt to future climate events. The word ‘adapt’ expresses the ability to adjust while accommodating to change. This definition of adaptation focuses on actions taken to adapt to actual or expected effects while moderating damage and exploiting valuable opportunities [2]. Resilience and climate adaptation are closely related, and both seek to create the capacity to adapt to climate events while maintaining the structure and function of cities. Moreover, both terms exclude mitigation strategies, which focus on the reduction of climate change [3]. The main difference between adaptation and resilience is in the scale of actions, as adaptation operates on a local scale [4], while resilience strategies include social, economic, and environmental aspects [5]. Adaptation strategies are inherent within social and ecological transformations, considering both the scope of actions and long- or short-term goals [6]. Therefore, climate adaptability is part of resilience strategies, and can thus be assessed with software tools on a local scale.

This paper seeks to explore the current digital tools that support the analysis of adaptability to climate change. The scope of this research is limited to software tools that allow the measurement of different aspects of climate adaptability for outdoor analysis using a case study project – the new development of a 1.2 ha neighbourhood in Ulm, Germany. The majority of previous work on software tools simulating the climatic aspects of outdoor spaces has focused on the functionality of a single software tool [7-9], while only a few papers have compared the capabilities and simulations of several software tools [10-14]. However, there is scant research that integrates the ISO 25010 software quality framework into the analysis of software tools. Moreover, previous papers have failed to analyse whether the needs of planners and clients as decision-makers are met. Therefore, this research includes in-depth interviews with project stakeholders, analysing the most common issues and requirements while digitalising planning for climate change and foreseeing the impact of design on climate. Moreover, the objective experiments conducted with current climate adaptation planning tools seek to explore both the implementation processes and the capabilities and limitations of tools based on the ISO 25010 framework. This research is limited to the software tools that support climate adaptation planning for outdoor places, and excludes the features not relevant for climate adaptability. This encompasses the tools that enable the production of various types of information, including both simulations and calculations on various aspects of climate adaptability.

METHODS

This paper explores the limitations of current climate adaptation planning software tools by conducting objective experiments with these tools and interviewing different project stakeholders. The inductive approach chosen for this research seeks to find unexpected patterns between software tools during observations, instead of focusing on hypotheses [15]. Firstly, this research seeks to observe current problems with software tools, applying open-ended questions to identify: 1) the needs and expectations of project stakeholders regarding software functionality and the output of software tools. Then, observations during objective experiments focus on the specific quality characteristics derived from the ISO 25010 quality framework. Qualitative methods are used during these experiments to define the main advantages and disadvantages of each tool. Figure 1 illustrates the methodology of this research, outlining the main questions and methods.

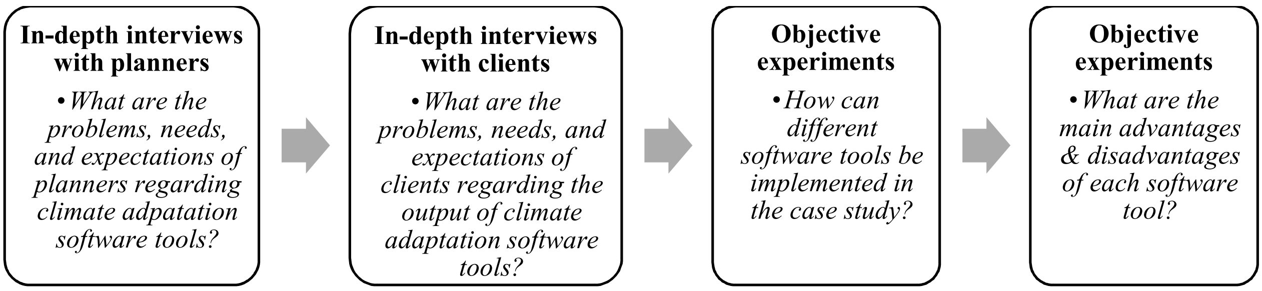

Figure 1. Research methods and primary questions.

Interviews with project stakeholders

Interviews with various project stakeholders were conducted to define the main issues with current software tools that can serve as barriers that hinder the digitalisation of climate adaptation planning. Then, the needs and expectations of planners and clients were analysed considering the academic background of the interviewee, their role in their organisation, and the organisational environment, size, and location. In total, 8 interviews were conducted with different planners and clients, each lasting up to half an hour. To achieve precision and correctness, in-depth interviews were conducted using open-ended questions which assist in providing new perspectives [16]. The main topics for questions were identified using the ISO

25010 framework, with a focus on functionality, information quality, and compatibility. Questions to planners focused on their roles as current or potential users of climate adaptation software tools, while questions to clients focused on the output of these tools.

Objective experiments

Objective experiments were conducted to identify the main capabilities and limitations of different climate adaptation planning tools. The case study project chosen for this research implements several climate adaptation measures, enabling comparison between simulations and calculations on climate adaptability. The SketchUp model – with buildings, streets, trees, and green and blue areas – was implemented in different software tools. The implementation of one model across different software tools allowed for comparison between the capabilities and limitations of different aspects of each tool. All tools were used for the same function: evaluating the climate adaptability of the design of the case study. It should be noted that some tools possess a wider range of functions that were not included in this research.

Firstly, the evaluation framework that allowed the comparison of different software tools was created using the ISO quality model. This framework included functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability [17]. The aspects targeted in this research included software functionality, performance efficiency, reliability, usability, and compatibility. Additionally, an analysis on information quality was conducted in order to compare the final results of different software tools, evaluating the accuracy of the information and its suitability for assessing climate adaptability. The functional capability testing of tools included an analysis of compliance with sustainability certifications such as LEED, BREEAM, and DGNB. The main targets and measures of each parameter are explained in the extended research in Table 1, combining quantitative and qualitative methods [18]. This paper implements qualitative methods to describe the main advantages and disadvantages of each tool using the adjusted ISO quality framework illustrated in Figure 2.

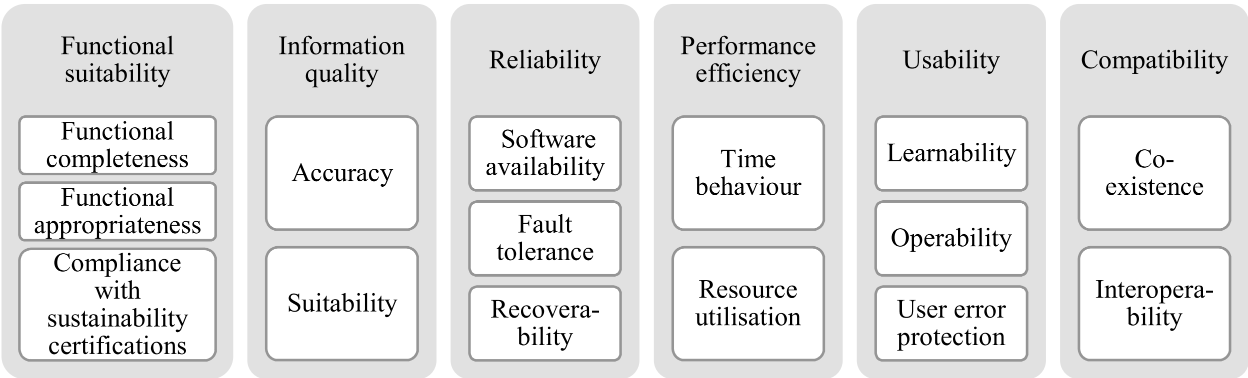

Figure 2. Software quality model based on the ISO 25010 standard.

RESULTS

Barriers to the digitalisation of climate adaptation planning

Interviews with planners and clients helped to identify the main barriers to the digitalisation of climate adaptation planning. Interviewees described the current issues that they experience with software tools, alongside their needs and expectations regarding software functionality and output. Firstly, some clients noted that most of their projects are not suitable for these tools, as sketches or project references supported by information on climate adaptation are largely acceptable. Moreover, clients noted that the output of software tools does not always convince them, and instead causes them to question the value of these tools. Other results from the interviews show that planners are keen on implementing digital tools that provide justification for their design decisions. According to the respondents, the main barriers to the implementation of these tools are a lack of time, budget, and experience of using specific tools. Additionally, some planners mentioned that the current tools lack important functions and require specific data, which is not always accessible. Overall, most of the issues identified by planners in the interviews were related to interoperability, data accessibility, and loss of information.

The expectations of various planners indicate how climate adaptation software tools might be improved and which functions are still missing. The most common issues with climate adaptation software tools were related to multi-functionality, adaptability to different projects, and user interactivity. However, the need for software functions varied between interviewees depending on their projects, backgrounds, and personal preferences. Despite these differences, the majority of planners mentioned the deficiency of simultaneous feedback on design solutions, which would allow them to compare different design scenarios efficiently and effectively. Additionally, adequate navigation was identified as an important characteristic, as this can ensure efficient usage of the software tool. Finally, expectations regarding software output were contradictory between planners and clients: some preferred the visual form of information, while others focused on storytelling methods based on adaptability calculations. Clients generally questioned the need for simulations on climate adaptability, whilst planners mostly identified them as rather useful tools.

The implementation processes of different software tools

The analysis of the implementation processes of five different climate adaptation planning tools in the case study project revealed issues on software interoperability and data loss. The implementation processes were tested using the same model containing the same data on materiality. However, some tools required remodelling to process data on climate adaptability, including AST and GreenScenario. The latter is based on 2D drawings imported into Rhino, where the model is generated using a visual script, whilst AST is an online tool based on the predefined process of climate adaptation planning that allows the location of different climate adaptation measures to be defined. Despite this strength, AST is characterised by numerous inaccuracies due to its map-based interface. The most efficient implementation process was observed when using Ladybug, which operates within the Rhino software tool. ENVI-met is the only software tool that provides an application for SketchUp, thereby supporting the transit of the model with information such as materiality, specific objects, and a grid system. However, this transition process exhibited several issues, causing both data loss and errors. Figure 4 summarises the results of the above comparison, presenting maps of the implementation processes of different climate adaptation tools including the sequence of steps used to produce simulations or calculations on climate adaptability. These results show that the ENVI-met software required the highest number of steps to implement due its interoperability issues. The LadyBug and GreenScenario tools allow for various formats of models to be imported but require knowledge of visual scripting to set up the script. The AST tool is the most elementary online tool and allows the effectiveness of climate adaptation measures to be efficiently compared, although scale issues do not allow accurate drawings to be produced.

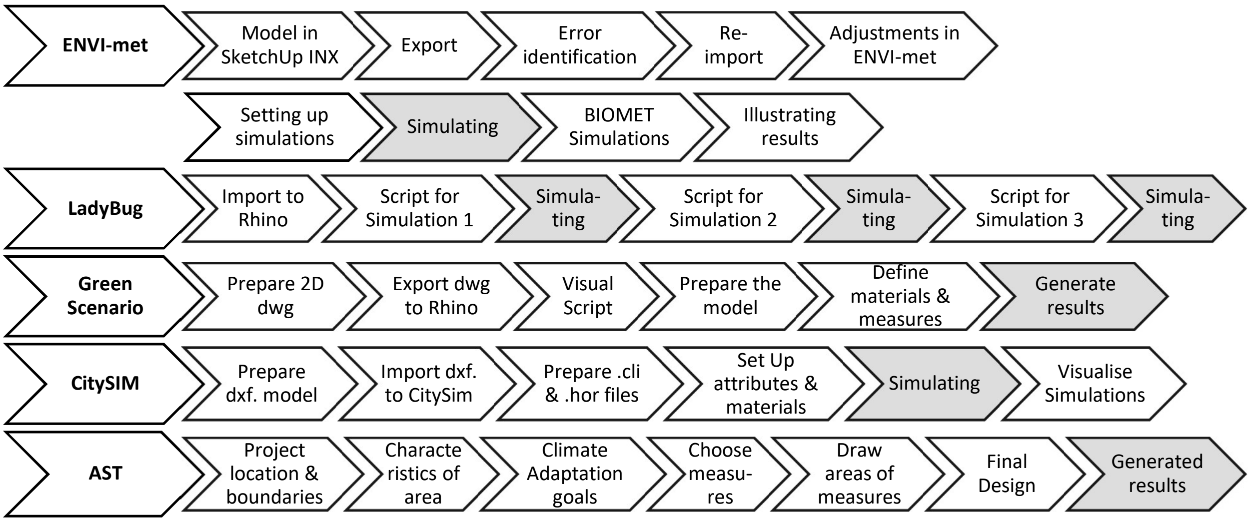

Figure 3. The implementation processes of various software tools in the case study project.

Overview of advantages and disadvantages

Objective experiments based on assessing quality characteristics from the ISO 25010 standard revealed that each tool possesses some limitations. Firstly, despite its complexity, long simulation process, and low model reusability, ENVI-met can produce a highly accurate, varied array of simulations in both 2D and 3D formats using local climate data. Despite the need for visual scripting knowledge, Ladybug was one of the most efficient tools for use in the case study project, allowing simulations to be produced with highly adjustable scripts and attractive visual presentations. However, the production of the correct script requires specific knowledge on microclimate calculation formulas. Correspondingly, the effectiveness of GreenScenario is based on visual scripting skills, but the tool has an additional interactive dashboard, presenting real-time calculations on different climate adaptation topics including stormwater, biodiversity, costs, CO2 emissions, and uptake. GreenScenario can be implemented more efficiently using a 2D drawing with closed polylines. AST software evaluates water pollution, water capacity, and heat reduction, assessing each climate adaptation measure separately. However, AST and CitySIM are both plagued by the low accuracy of their produced outputs; moreover, CitySIM has the longest simulation process, limited functionality, and low adaptability for climate adaptation projects. Table 1 summarises the advantages and disadvantages observed during the objective experiments, using software quality characteristics derived from the ISO 25010 framework.

Table 1. The advantages and disadvantages of various climate adaptation software tools.

		ENVI-met	Ladybug	CitySIM	AST	GreenScenario
Functional Suitability	Adv.	- Wide range of climatic analysis; -3D vis. of data;	- Individualisation;	-Simple interface;	- Individualisation;	-Individualisation; -Interactive Dashboard;
	Dis.	-Simple functions such as 'undo' are missing;	-Limited by visual scripting knowledge;	- Functionality; - Low individualisation;	-Lack of drawing tools;	-Limited by visual scripting knowledge;

Information Quality	Adv.	-Precise simulations; - Model check;	-Variety of visualisation styles;	-3D visualisation of simulated data;	-Calculations in real-time;	-Visually comparative analysis;
	Dis.	-Simulation errors at the edges;	-Risk of errors in the script;	-Low precision of simulations;	-Low accuracy;	-Risk of errors in the script;
Reliability	Adv.	-High reliability;	-High reliability;	-High software availability;	-No installation needed;	-High reliability;
	Dis.	-Issues in SketchUp INX;	-Low protection against faults	-Recoverability, with exceptions;	-Low reliability;	-Low protection against faults;
Performance efficiency	Adv.	-Contains several applications for different functions;	-Fast simulation results;	-Simple interface;	-Calculations in real-time;	-Calculations in real-time;
	Dis.	-Long simulation duration; -Complex interface;	-Potential errors in the script;	-Long simulation duration;	-Depends on the complexity of climate adaptation measures;	-Potential script errors;
Usability	Adv.	-Model check against errors;	-Individualisation of the script;	-Simple interface; -Intuitive to use;	-No software knowledge is needed; -Simple use;	-Individualisation of the script;
	Dis.	-Complex structure of tools and applications;	-Visual scripting knowledge required;	-Simulations require specific climate files;	-Lack of tools such as tracing function;	-Visual scripting knowledge required;
Compatibility	Adv.	-Compatible with other tools,	-High level of interoperability	-High level of interoperability;	-Online-based design process;	-High level of interoperability;
	Dis.	-Limited interoperability -Errors during export;	-Script data not compatible;	-Risk of data loss;	-Low interoperability;	-3D model must be generated in Rhino;

DISCUSSION

Implementing climate adaptation software tools

This paper presents the results of an analysis of the implementation processes of five different software tools in the same 3D model in a case study project. The implementation process maps produced from objective experiments testify to both software performance and compatibility. These results reveal that most of the software tools studied allow the implementation of 3D models from other common software tools except the AST tool. Additionally, these experiments show that some tools are better at integrating other types of formats; for instance, GreenScenario allows a 3D model to be efficiently generated from 2D polylines. The results of this paper are limited to the specific case study project and the model used for the objective experiments. Moreover, the objective experiments were conducted by a single user, eliminating the evaluation of subjective areas such as the aesthetics and recognisability of the software interfaces. Future research could conduct more experiments with different users and different projects to compare and verify these results. An overview of the wider literature reveals a lack of comparative research on the implementation processes of various software tools. Some papers focus on the implementation process of a single tool, without the integration of a diverse range of tools that would allow for comparisons of their capabilities and effectiveness [7-9]. Other papers focus on the results of simulations, thereby excluding the process of implementation [10-12]. However, the analysis of implementation processes presents an example of how climate adaptation software tools can be implemented in practice, helping to promote the digitalisation of climate adaptation planning.

The implementation of the ISO 25010 framework

This paper discussed the advantages and disadvantages of different software tools that were identified during the experiments. These observations focused on the quality characteristics defined using the ISO 25010 framework, which includes the most important aspects for software users that strongly influence their results. The literature review indicates that most papers focus on different quality aspects, without the implementation of the ISO 25010 quality model. Vidmar and Roset [13] compared functionality, user interface, usability, and ease of use; however, this paper excludes analysis on important aspects such as software reliability, compatibility, and information quality. Al-Bdour and Baranyai [14] focused on software reliability, information accuracy, compatibility, user interfaces, graphics, and the comfort prediction index. Some of these aspects are covered in the ISO framework, and while user interface and graphics play an important role in software usability, the evaluation of graphics and user interface are highly influenced by user preferences, reducing the objectivity of results. Therefore, analysis of these aspects should include more users to validate results. This paper seeks to reduce subjectivity by eliminating analysis of user interface aesthetics and focusing instead on measurable qualities. To conclude, the ISO framework gives comprehensiveness to results when comparing the most important qualities of software tools.

CONCLUSIONS

Interviews with project stakeholders identified the main barriers to the digitalisation of climate adaptation planning. Firstly, current climate adaptation software tools lack efficiency, interactivity, and adequate adaptability to different projects. Secondly, the value of climate adaptability simulations is questioned by clients. Furthermore, objective experiments with five different climate adaptation software tools revealed the main advantages and disadvantages of the functionality, performance efficiency, reliability, usability, and compatibility of each software tool. These results show that the current tools are beset by a number of limitations, including software interoperability, causing data loss; and performance efficiency, requiring significant time resources to produce precise simulations.

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