Digitalization of climate adaptation planning: the potential of simulation software tools for landscape design

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Abstract. Climate change plays a significant role in the landscape architecture discipline seeking to solve the problems related to floods and heatwaves. Climate adaptation planning deals with a high level of uncertainty while precipitating future climate events to prepare adaptable landscape designs. However, digital technologies are rarely implemented into landscape design projects with deep environmental concerns. Meanwhile, digital tools have the potential to improve climate adaptation planning while calculating and simulating the adaptive capacity of design. Therefore, this research investigates the capabilities and limitations of software tools suitable for climate adaptation projects. The software tools are evaluated using the ISO 25010 framework comparing their capabilities. The main method used for this research is based on objective experiments while implementing different software tools to conceptual landscape design on a case study project. The experiment revealed that the implementation process deals with many limitations including interoperability and data loss. Moreover, this research conducted in-depth interviews with project stakeholders including planners and clients to identify their problems, needs and expectations regarding software tools. Finally, the roadmap on the software selection resulting from this research provides the guidelines on how to select the most suitable tool for various climate adaptation projects.

1. Introduction

Climate change challenges planners to consider the higher risks of floods and prepare adaptable plans coping to handle weather events. Currently, the financial losses due to climate change reached €95 billion within ten years counting from 2002 to 2012 [1]. Moreover, it is predicted that the costs for the damaged facilities due to floods and storms will continue growing as climate change is further accelerating [2]. Therefore, the demand for adaptable design moderating the damage caused by climate change is growing. However, climate adaptation deals with high complexity requiring digital tools to evaluate the effectiveness of the adaptable design. Currently, digital software tools are not fully integrated into the planning process due to the low expertise and insufficient data allowing to assess the benefits of climate adaptation measures [3]. The digitalisation of climate adaptation planning enables analysis of complex data helping to reduce the failures in planning and decision making. Therefore, the focus of this research is the digitalisation of climate adaptation planning using the software tools enabling simulations and calculations on climate adaptability. This paper examines five different climate adaptation software tools including ENVI-met, Ladybug, GreenScenario, AST (Adaptation Support Toolbox) and CitySim. These tools are examined in the objective experiments implementing them on the case study project, a neighbourhood in the outskirts of Ulm. The capabilities and limitations of these tools are compared using the ISO 25010 quality model. Moreover, the results are correlated identifying the needs and expectations of different project stakeholders including planners and clients in the interviews. Finally, the research proposes the roadmap helping to select the suitable tool for various climate adaptation projects. Figure 1 illustrates the framework of research defining the methods used to collect data at different stages.

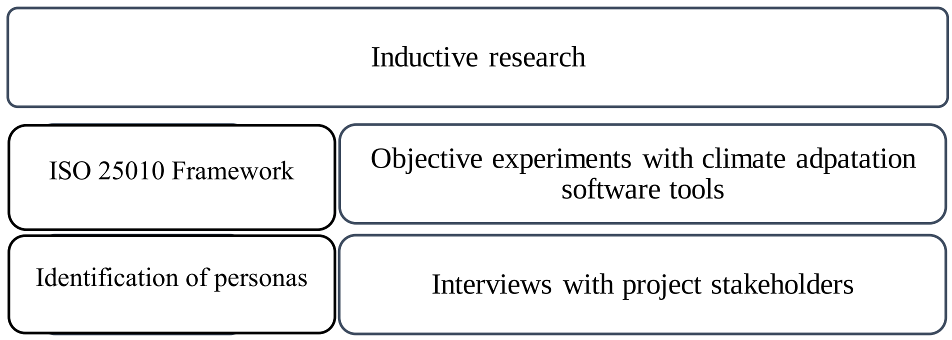

Figure 1. The framework of research (source: authors)

2. Literature Review

The review of the literature on climate adaptation simulation software tools revealed that the centre of focus is primarily on the analysis of functionality of single software, focusing on the impact of vegetation on the microclimate [4-10], or urban form [11-13]. While majority of these studies focus on a single software tool, while only a few studies compared several tools focusing on various aspects of software characteristics. None of the reviewed paper implemented the ISO software quality framework for the comparison of climate adaptation software tools. Therefore, high variety of quality measures are assessed in various researches. Some papers analysed different aspects of climate adaptation such as thermal comfort analysing user interface, reliability, software cost, compatibility, visualisation and comfort prediction index [14]. The comparison of software technical availability of elements informs the applicability of the software tool for different projects, however the evaluation of user interface is rather a subjective matter, as it is based on a single opinion and personal preferences. Other research on thermal comfort compares three different tools analysing software suitability for climate adaptation simulations [15]. It presents a good sample of how to choose the software tool for the particular landscape architecture office but the roadmap on software selection applicable for various companies is rather missing. Other research focusing on the functionality and usability of tools are focused on the measures of physical processes such as air exchange, heat exchange, radiation, irradiation, evaporation and acoustics [16]. However, most of the climate adaptation measures are not included in this research.

To conclude, a literature gap was identified in the evaluation of climate adaptation simulation software tools based on the ISO framework and the requirements for sustainable planning regarding climate adaptability such as BREEAM, LEED and DGNB. Furthermore, there is a lack of research analysing different software tools for landscape projects defining the roadmap for software selection. Therefore, this research will analyse different software tools for landscape design adaptation to climate change proposing a roadmap on the suitable tool selection based on specific climate adaptation projects.

3. Research Methodology

3.1. Approach on research

This research seeks to identify the capabilities and limitations of climate adaptation software tools and the needs and expectations for these tools from project stakeholders using an inductive research method. The inductive approach seeks to find unexpected patterns while observing multiple facts without creating a pre-defined hypothesis [17]. This method is the most appropriate for this research based on objective experiments with software tools and stakeholder interviews seeking to define various needs, expectations and problems related to software use and implementation. Furthermore, the ISO quality model is implemented to achieve expedience in the objective experiments with software tools by identifying the main quality characteristics to analyse during the experiments. Moreover, the interviews based on open-ended questions are proceeded with different project stakeholders to identify various personas and their needs.

3.2. Data collection and data analysis

3.2.1. Integration of the ISO 25010 framework

The ISO 25010 standard is integrated into objective experiments to analyse climate adaptation software tools in the conceptual design planning phase. The ISO quality model can be integrated for climate adaptation software comparison adjusting the standard quality model. Firstly, the applicable quality requirements are chosen identifying the reference values and targets [18]. Further on, quality measures are determined and compared with values and targets.

The ISO 25010 quality model was implemented in objective experiments as the framework with the predefined software quality measures including software functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability [19]. The ISO framework was adjusted for the climate adaptation case study project and applied in the objective experiments with the residential urban quarter in the city of Ulm. Firstly, this research excludes the analysis of software maintenance aspects, software portability and security. Furthermore, the subjective evaluation of software appropriateness, recognisability, capacity, maturity and user interface aesthetics are excluded from the research to achieve higher objectivity comparing software tools. This research focuses on software functionality, the information quality, reliability, performance efficiency, usability and compatibility. The functionality of the software tools is evaluated by analysing functional completeness, appropriateness and compliance with sustainability certifications such as BREEAM, LEED and DGNB. Functional completeness evaluates features suitable for climate adaptation measures such as blue and green infrastructure, climatic parameters and economic value. While functional appropriateness focuses on the process maps and time register. Further on, information quality evaluates the accuracy of simulations and information suitability for climate adaptation planning. Furthermore, software reliability is assessed by calculating the number of incidents and errors. Moreover, performance efficiency focus on time resources use to perform the same task with different software tools and the list of resources such as expert guidance, tutorials and external data. Meanwhile, usability analyses the time used for training reflecting software complexity. Finally, compatibility focus on the software implementation process including time resources. Table 2 summarises the quality characteristics assessed in the objective experiments defining the measures and targets of evaluations based on the ISO 25010 definitions. To analyse the quality parameters of software tools qualitative and quantitative methods are chosen regarding the measurable characteristic and their targets. For instance, time, incidents and error register present quantitative values measured for different quality characteristics, while different types of observations implement qualitative methods.

Table 1. Software evaluation framework for climate adaptation software based on ISO 25010 standard [20].

ISO Requirements	Description	Targets	Measures
Functional Suitability			
Functional completeness	Analysis of various aspects of climate adaptation covered in the software	Evaluation of the software's functions	Observations
Functional appropriateness	The accomplishment of the task excludes unnecessary steps	Evaluation of process maps	Process maps and time register
Compliance with sustainability certifications	The analysis of the aspects of sustainability covered.	Evaluation of the software's compliance with sustainability standards	Aspects defined in sustainability certifications;
Information Quality			
Accuracy	How accurate are the simulations or calculations	Evaluation of the accuracy of simulations	Visual and digital comparisons
Suitability	How the software informs on the climate adaptation performance	Evaluation of how the results inform on climate adaptation planning	Climate adaptation targets
Reliability			
Software Availability	Evaluation of the software's reliability	Calculation of incidents of the software 'not responding'	Incidents register
Fault tolerance	Evaluation of the software's operation despite hardware or software faults	Calculation of errors and failures	Error register
Recoverability	The software can recover data in case of interruption.	Evaluation of recovered data in case of system error	Observations
Performance efficiency			
Time-behavior	The time needed for task processing and simulations	Calculation of time used per task	Time register
Resource utilisation	Resources needed for tasks (excludes productivity)	Evaluation of the resources (expert consultations, training material, other files and software tools) needed to perform the task	List of resources
Usability			
Learnability	Time to learn to use the software for climate adaptation functions	Calculation of the time for training	Training time register
Operability	The software can be easily operated after having been learnt.	Evaluation of the software's complexity	Observations
User error protection	The software can help users to avoid errors	Evaluation of error identification	Observations
Compatibility			
Co-existence	The software performs efficiently, sharing a common environment and resources with other software tools	Evaluation of how the software is compatible with other software	Implementation process maps and time register
Interoperability	The software can exchange and use the information from other software	Evaluation of the data lost or geometrical issues in the exportation and importation	Observations

The ISO framework was integrated into the experiments with climate adaptation software tools. There are various types of experiments depending on the control levels such as controlled, observational and quasi-experiments [21]. The experiments with different software tools integrate observational methods

based on monitoring of defined quality characteristics from the ISO framework. The challenge of this type of study is the control of objectivity while comparing the capabilities of software tools. Therefore, the research eliminates the analysis on subjective areas including user interface, appropriateness, and recognisability. Moreover, the analysis of software tools focuses on the measurable parameters such as processing time of each task, simulation results, the number of errors and failures. The variables of the experiments are reduced using the same computer device, project and settings where possible. The same 3D model was prepared and implemented in five climate adaptation software tools, including ENVI-met, Ladybug, GreenScenario, CitySim and AST (Adaptation Support Tool). These tools are selected according to their accessibility and suitability for the evaluations of the climate adaptability of landscape design.
The case study used to perform objective experiments is a residential area developed in the outskirts of the fast-expanding city of Ulm. The neighbourhood integrates a number of climate adaptation measures including retention swales, water retention pond in the central park accumulating the rainwater of 100-year climate events. The project is nominated as the best waste management project in Bayern. Residential units are one of the most vulnerable areas to climate change due to the dense social structures, therefore this case study was chosen for this research.

3.2.2. Interviews with project stakeholders
A series of interviews were conducted as part of the data collection process to identify the main issues with software tools. The interviews aimed to define the needs of planners corresponding with client expectations. Moreover, the needs of different stakeholders were researched based on the identification of different personas, typical to their relative roles and representative organisations. Therefore, individual in-depth interviews were conducted to form different personas typical for their role and study their needs. Moreover, open-ended questions help to identify new propositions [22]. Furthermore, in designing the interview questions special effort was made to align them with the ISO framework, questioning the need for software functionality, information quality and compatibility to allow the correlation of interview results with the objective experiments.

3.2.3. Interviews with planers
The interviewees were first selected to represent different sizes of companies, with different roles and academic backgrounds including architects, landscape architects and urban planners from different countries. The main goal was to identify the current use of digital software tools for landscape adaptation planning, their expectations and their needs regarding software functionality, performance, efficiency and compatibility. Moreover, the issues and challenges of digitalisation of climate adaptation planning were discussed during the interviews. Finally, different personas and their needs and expectations were identified.

3.2.4. Interviews with clients
Further on, the interviews with clients procuring climate adaptation projects were conducted identifying different personas. The interviewees were selected from private companies and city representatives with different experiences. The focus of the interviews was the expectations and needs regarding climate adaptation software output for the conceptual design phase. The interviews integrated open-ended questions allowing to follow the specific needs of each persona.

3.3. Limitations
The investigation of climate adaptation tools is based on the objective experiments conducted by one person. To prove the results further investigations could integrate more users to perform the same tasks. Moreover, the subjective software quality aspects such as user interface analysis could be proceeded with different software users. Additionally, the results of this research are highly influenced by the case study as a different project can cause different issues using the same software tools. Furthermore, this research integrates only the software tools which were shared for this research.

4. Findings and Discussion

4.1. ISO 25010 software quality model

The ISO framework implemented to the evaluation of climate adaptation planning software tools allows efficiently compare the tools, their capabilities, strengths and weaknesses. However, the ISO framework is rarely integrated into other researches as a tool for the evaluation of climate adaptation software tools. Therefore, different papers focus on other software quality measures. For instance, Vidmar and Roset [16] evaluate software functionality, usability, user interface and ease of use. However, the research covers only functionality and usability according to ISO 25010 quality model and definition. While, Albdour and Baranyai [14] analyse user interface, software reliability, information accuracy, compatibility, graphics and comfort prediction index. According to the ISO framework, this research partly covers software usability and information quality while different criteria are used for software reliability and compatibility. Additionally, the evaluation of software graphics and comfort prediction index is not defined by ISO and deals with a high level of subjectivity but are relevant features for software usability. Diéguez et al. [15] analyse the usability of the software focussing on time efficiency, cost, output, adaptability, flexibility, compatibility and information reliability in terms of technical measurements. Moreover, other software features are compared such as learning curve using exiting knowledge, possible continuation of software usage and support possibilities. However, the structure of evaluation is rather chaotic with different definitions of quality characteristics in comparison to the ISO framework. Therefore, none of the papers includes a well-structured framework for software comparison covering a wide range of software qualities. This paper creates the guidelines on ISO quality model integration while selecting climate adaptation software tools. The results revealed that ISO quality characteristics cover the most important features for software comparative analysis and have high adjustability for specific fields. This research adds information quality as an important characteristic for data rich models. The objective experiments comparing five different software tools based on the ISO framework helped to identify the most effective software tool for each quality characteristic. Figure 1 illustrates the results on climate adaptation software strengths and limitations. The scores are given using a comparative principle from the highest score 5 to the least 1. The results show that the strength of ENVI-met is information quality but rather weak in compatibility and performance. While AST is weak in information quality but has high performance and usability rates. The highest overall score was collected in Greenscenario which is leading in functionality, reliability and compatibility with Ladybug. However, the weaknesses of Greenscenario is usability and performance. To conclude, each software tool deals with some limitations and deficiencies requiring to consider the priorities of each quality characteristic while selecting the software tool for climate adaptation projects.

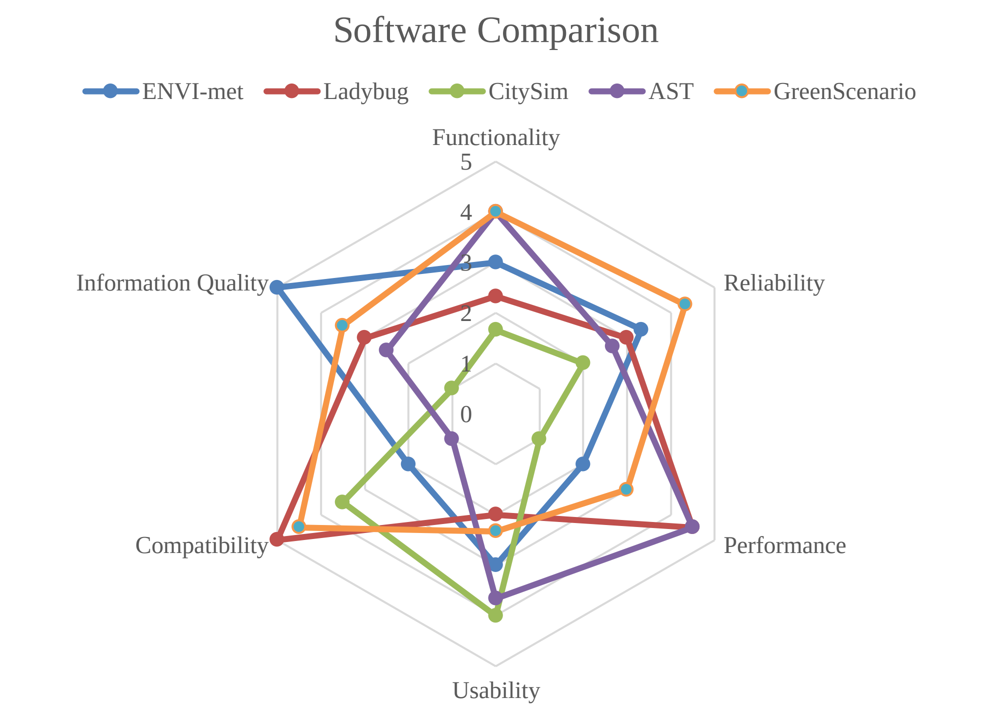

Figure 2. The comparison of software tools concerning different ISO 25010 aspects [20]

4.2. *The needs of planners and clients*

The literature review revealed the lack of analysis considering the needs of different project stakeholders. McEvoy [23] conducted semi-experiments with several climate adaptation software tools focusing on the comparison of the working process and collaborative-ness using different tools and tool-free approach. However, this research excludes the analysis of technical issues, the needs of planners and clients using these tools. Therefore, this paper conducted interviews with several types of planners and clients aiming to identify the current digitalisation level of climate adaptation projects and the needs of planners and clients. Moreover, the expectations from planners and clients were compared identifying the current gaps in the software tools regarding functionality, effectiveness and output. The interviews revealed different needs and expectations from planners and clients regarding climate adaptation software tools. The differences were mostly determined by their organisational values and environment.

Firstly, the interviews with clients generated four different personas with different expectations. Some clients identified the need for the climate adaptation information and its issues expressed visually. Meanwhile, others see the value of scientific calculations strengthened with storytelling. Therefore, the selection of software tools should consider the type of clients, their needs and expectations. However, most of the clients expect typical climate adaptation parameters considered in the landscape design such as temperature, wind and heat. Mostly, the clients expect information on flood management defining the design capacity to manage rainwater. However, simulations on flood manageability are rarely expected from the clients. Generally, the implementation of climate adaptation software tools is rather low and the potential of these tools is not always convincing. The main challenges for software implementation identified during the interviews are costs and suitable projects.

Furthermore, the interviews with four different planners working in different sizes of the organisation revealed different needs and expectations on climate adaption software tools and challenges for implementation. Most of the small and medium-sized companies had low financial resources to implement new software tools for climate adaptation planning. Moreover, most of the planners identified the need for software adaptability to different projects and the multi-functionality of one tool. However, the need for functionality varied between different personas depending on their working methods and style. Some planners defined the need for climate and flood management related information while others emphasize the combination of economic, environmental and social aspects, the latter is hardly measurable. Moreover, the most issues between planners identified in the interviews were interoperability, data accessibility, and loss of information. The functions often missing in the climate adaptation software tools include interactivity and continuous feedback on design decisions.

To summarise the results from interviews, the planners often deal with technical issues implementing climate adaptation software tools including interoperability, data accessibility. However, clients often question the value of the additional time and cost. Therefore, the expectations from planners regarding the output of software tools often are not matching with the client needs. Hence clients often accept sketches with the information, sample projects and the story behind the design. However, the planners mentioned the need to produce microclimatic visualisations with software tools. Table 1 summarises the results from interviews with planners and clients identifying the main problems for software implementation, expressing different needs and expectations.

Table 2. Summary of planners and clients problems, needs and expectations for software tools supporting climate adaptation planning (source: authors).

	Planner 1	**Planner 2**	**Planner 3**	**Planner 4**	**Client 1**	**Client 2**	**Client 3**	**Client 4**
Persona	Project manager; Landscape arch.; medium org., Uberlingen, UK	Project manager, Landscape arch. small org., Hamburg, DE	Owner & Project manager; Architecture urban planning; small org., London, UK	Project Manager, Water Eng.; Large org.; Copen-hagen, DK	The city officer, Ulm, DE	The private company in cooperation with city; Hamburg, DE	Private developer, Hamburg, DE	Private developer, Heidelberg, DE
Problems	Interopera-bility; Data accessibility Mono-functional software.	Need of licenses; very narrow application of tools; complicated use; need of specific knowledge and data;	Not technical issue; A long explanatory process on the needs and the benefits of climate adaptation.	Interopera-bility, Loss of information, data accessibility A long explanatory process on climate adaptation awareness;	Not always convincing; unbalanced costs with the value;	Time and costs;	Time and costs; A slow process of simulations; Mono-functiona-lity	Lack of suitable projects to implement;
Needs and Expectations								
Information needed for climate adaptation planning	Shading, sun hours, heat map	Shading, air tempera-ture, flood risk, water flow: grey and stormwater Water pollution, soil condition	Social, economic and environ-mental aspects Benefi-ciaries;	Stormwater; Flood risk, flood protection; Future rain events	Rain frequency, stormwater events, high water level, floods, mainte-nance;	Micro-climate; temperature; the potential of the area;	Micro-climate: temperature, wind; noise, pollution, water retention potential;	The value of green areas;

Functionality	Easy navigation; Comparison of different design scenarios; visual analysis of climate data.	The impact of topography on micro-climate; the dispersion and flow of pollution.	Interacting dashboards showing the change.	Interactivity with the tools; Interconnection between tools; Simultaneous feedback on the design process.	-	-	-	-
Visual Output	Wind, heat effects, sun hours, stormwater, soil quality and management	Disperse of air pollution, wind movement (tunnels), the impact of materiality.	Visualisation is an emotional tool, Storytelling is essential.	Visualisation of information; Comparative visual tools for various scenarios.	The photo of the sample project	Storytelling;	Simulation and visualisations for comparisons	Sketches with information on climate impact;

4.3. Roadmap on software selection

The literature review identified the need for guidelines or roadmap helping to select the appropriate software for climate adaptation projects. A number of papers evaluated different aspects of software tools such as functionality, usability, user interface and ease of use [16]; user interface, software reliability, information accuracy, compatibility, graphics and comfort prediction index [14]; the price of software and the flexibility [15]. However, the overview of the ISO 25010 software quality characteristics is currently not integrated into other papers. Therefore, a roadmap helping to select the most suitable tool for planners seems to be missing. The need for clear guidelines showing how to integrate software tools for climate adaptation projects helps to foster the digitalisation of climate adaptation planning. Consequently, the paper proposes a roadmap considering the specifics of climate adaptation projects, the needs of project stakeholders and the ISO software quality measures.

First, the software selection should consider the objectives of climate adaptation planning setting up the KPIs (Key Performance Indicators) to measure the effectiveness of the climate adaptation design. As the software should demonstrate the ability to measure the identified KPIs. The KPIs for climate adaptation planning can be oriented towards sustainability certifications such as LEED, BREEAM or DGNB. Furthermore, the needs, time resources and expectations of the client needs to be defined and addressed in the software selection phase. For instance, the interviews revealed that the information on climate adaptation planning is better perceived visually or verbally depending on the persona. The selected software tools meeting the expectations of project stakeholders and KPIs should be tested on similar projects. The comparison of these tools is recommended to be proceeded implementing adjusted ISO 25010 quality model with the prioritised quality characteristics. Finally, the evaluation of the software tools is based on the ability to cover the most important quality aspects. The figure below illustrates the roadmap recommended for the software selection on climate adaptation projects based on the results of this research proceeded on the case study project, adaptable residential neighbourhood in the suburbs of Ulm city.

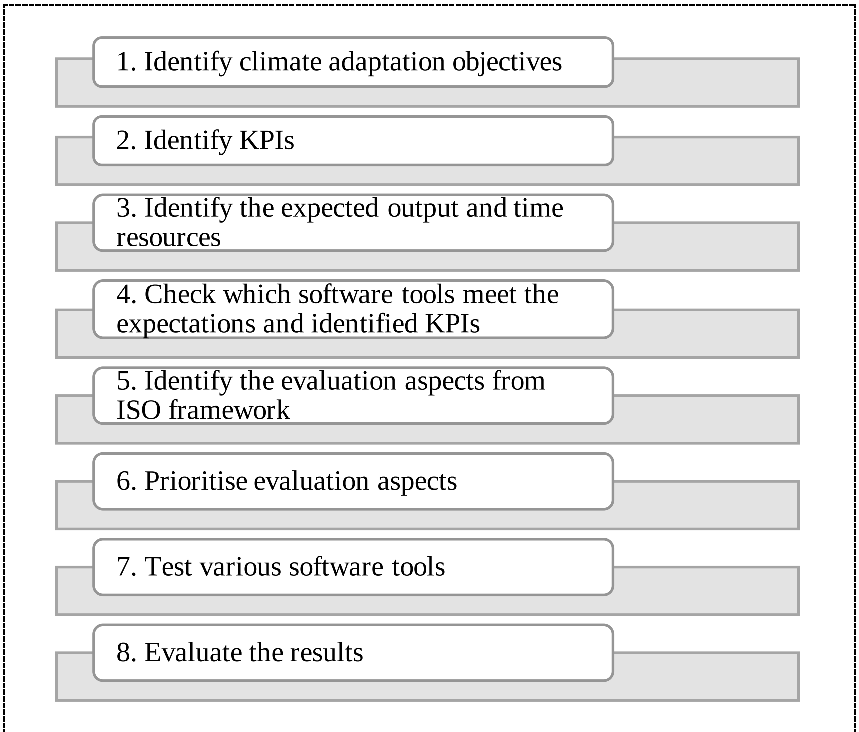

Figure 3. Software selection roadmap (source: authors).

5. Conclusions and Further Research

The paper analysed various climate adaptation tools implemented for the case study comparing their capabilities and limitations while using the ISO framework. The comparative analysis based on the objective experiments showed that tools have different strengths and weaknesses on different quality measures defined by the ISO quality model. The results showed that the tools deal mostly with interoperability and data loss. Moreover, the functional analysis of the tools showed that some tools can cover wide range of climate adaptability measurements and different requirements of sustainability certifications including DGNB, BREEAM and LEED. Howoever, the comparison of their requirements identified some variations on the requirements for the adaptive neighbourhoods. Moreover, the tools producing high quality data require high time resources for training and for producing simulations respectively. The interviews with the project stakeholders revealed that high quality simulations are often not required from the clients but the planners expect to analyse various parameters relevant to climate adaptation planning process while implementing efficient, multifunctional and interactive digital tools. The findings from the objective experiments and interviews resulted in formation of the roadmap defining the main steps to consider while selecting the software tool for various climate adaptation projects. The findings of this research play an important role for the digitalisation of climate adaptation planning. The future research could investigate the findings on software capabilities integrating more participants in the objective experiments and the implementation of these software tools to different type of climate adaptation projects.

6. Appendices

Interviews with planners

Aim to identify the needs and expectations of planners regarding the software tools for climate adaptation.
Types of planners: standard – less digitised working method; Using digital tools;

Type of organisation: small business, medium company, large company
Discipline: urbanism, landscape etc.

Questions to planners:
1. What type of analysis do You need to deliver in practice for climate adaptation projects?
2. What type of information would help to improve climate adaptation design?
3. Which software tools do You currently use for climate adaptation simulations?
4. Which functions are you currently missing in the software tools for climate adaptation planning?
5. What are the main problems in climate adaptation planning software in practice?
6. Which tasks in climate adaptation planning require the most time resources?
7. How much time can You invest to learn new software for simulations?
8. What are Your expectations from the software tools supporting climate adaptation design?

Interviews with clients

Aim to identify the needs and expectations of clients regarding the results of climate adaptation planning with software tools.
Types of clients: private developers and cities; different visions: environment against commercial benefits.
Questions to clients:
1. What impact have the visualisation of information on climate adaptability to the final decision on the design?
2. What visual methods/techniques of landscape design adaptation to climate change are the most appealing?
3. What type of information for the landscape design adaptation to climate are the most important?
4. What information on landscape design adaptability is often missing?
5. What type of simulations for the landscape design adaptation to climate are mostly required?

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