VisAdapt: A visualization tool to support climate change adaptation

Jimmy Johansson[a], Tomasz Opach[b], Erik Glaas[c], Tina-Simone Neset[c], Carlo Navarra[c], Björn-Ola Linnér[c], Jan Ketil Rød[d]

[a]*Information Visualization Group, Linköping University / Norrköping Visualization Centre C*

[b]*Norwegian University of Science and Technology / Linköping University*

[c]*Department of Thematic Studies – Environmental Change / Centre for Climate Science and Policy Research, Linköping University*

[d]*Norwegian University of Science and Technology / University of Agder*

Abstract

In this article we present the design and implementation of the web-based visualization tool VisAdapt, developed to support homeowners in the Nordic countries to assess anticipated climate change risks, which are expected to negatively impact their living conditions and to identify possible adaptation measures. The tool guides the user through a three-step visual exploration process to facilitate the exploration of risks and adaptive action, specifically modified to the users' location and house type. We have developed VisAdapt over the course of three years in close collaboration with domain experts and end users to ensure the validity of the included data and the efficiency of the visual interface. Although Nordic homeowners are the targeted end-users of VisAdapt, the insights gained from the development process and the lessons learned from the project could be valuable for researchers in a wide area of application domains. These include how to make global changes tangible on the local level, how to develop easily accessible flow of information and how to incorporate end-user evaluations in the development process.

1. Introduction

Making the multifaceted information on anticipated climate change trends and impacts available to a wider audience is a challenging and demanding, yet important, task. Existing climate models are complex and based on vast amount of climate data. To properly convey and correctly interpret research results based on such models, one therefore requires adequate tools. Visualization – the process of forming a mental model of something by using visual representations[1] – is a proven technique for conveying large, complex and multifaceted datasets, as well as for translating these into applicable knowledge. Besides being an efficient means for conveying data, visualization has also the ability to attract the attention of a wide range of users, including those with limited experience.

Existing climate visualization tools are usually developed as web-based applications due to the ease of access for users. However, many of them are almost exclusively targeted towards professional users[2]. This makes the tools inaccessible to novice users, such as ordinary homeowners who normally do not have extensive knowledge on neither interactive visualization nor climate change. For visualization tools to be widely adopted by laypeople, these therefore need to be designed and developed so that the extensive information on climate change and impacts can be transformed to support *real individual decision processes and adaptation actions* in an easily comprehensible way. To successfully implement such tools it is vital to adopt graphical means for directing users' attention in the visual interface design, as well as to involve end users in the entire development process.

In this article, we propose and assess a visualization tool that aims to support climate change adaptation processes among regular homeowners. We have recognized this as a new application area for interactive visualization, not addressed thoroughly in the existing literature[3]. Although we focus on climate change effects in the Nordic region (Denmark, Finland, Iceland, Norway and Sweden), and demonstrate a specific web-based visualization tool called VisAdapt[4], our findings open the door to new possibilities for conveying complex climate change data to individuals through visualization. We address the challenge of designing a complex interactive visualization tool targeted at novice users, which, to the best of our knowledge, has not received thorough attention in the visualization community yet. To summarize, the main contributions of this article are:

- the design and assessment of interactive visualization techniques for novice users,
- the introduction of a complex, interactive visualization tool in the domain of climate change adaptation,
- lessons learned about design and implementation of visualization tools for lay people which is useful to consider also in other domains

Making such sophisticated tools usable for laypeople demands directing users' attention to the most important and most relevant parts of the visual interface. We address this issue by dividing the interface into three separate modules whose arrangement guides the user through the most relevant data for their place of interest. How to design such settings to support users to explore complex data is thoroughly discussed in the article.

2. The need for information on climate change and adaptation measures

During the last years, property damage due to weather related events such as flooding and storms has increased in the Nordic region. As a result, insurance companies have experienced an increase in the number of claims payments to homeowners. In the future, one expects damage costs to continue to rise due to anticipated climate change and weather related impacts such as: sea level rise, increased annual precipitation, increased number of days with heat waves, more common and intensified cloudbursts, increased number of landslide events and potentially more days with strong wind[5]. To be able to manage these impacts, it is important to facilitate adaptation planning among the most basic actors, i.e., ordinary homeowners, based on the latest scientific outcomes.

Easy access to climate data seems to be a basic condition for such planning. However, the amount of climate change related information has increased dramatically over the last few decades and the information is generally complex and thereby hard to grasp. Climate change scenarios, for instance, are calculated for different representative concentration pathways (RCPs) that in turn lead to different climate change projections. Therefore, providing individuals with such a massive amount of information is not enough to facilitate proper adaptation planning. For many people, the detailed information about projected changes, for instance, in annual mean temperature or the number of days per year with cloudbursts, is simply meaningless. To help individuals base their adaptation actions upon scientifically relevant information, auxiliary easy-to-understand information on local climate impacts (risks) and vulnerability has thereby an important role to play[6].

Even if individuals are aware of possible climate sensitive hazards resulting from changing climate conditions, they are still not necessarily able to undertake adequate adaptation actions. For example, if a user identifies increases in rainfall and floods to be a likely future scenario, it does not mean that she/he would know how to improve or manage the house in a proper way. Therefore, apart from improving information on climate and climate related data (i.e., on impacts, exposures, or vulnerabilities), one should provide ready-to-use and easy-to-understand adaptation measures linked with particular climate variables and impacts as well[7, 8]. With such information, even those who have very basic or no previous knowledge can make use of the information.

3. Related work on climate data visualization

Our work mainly relates to two research areas: visualization of climate change data and user-focused studies on tools supporting climate change adaptation.

3.1. Interactive visual interfaces to climate and climate related data

The growing complexity and number of climate models, the increasing amount of climate and climate-related data and the changing profile of their users have called for effective measures to support data communication, exploration, and analysis[2]. To address these issues, we propose solutions where climate[9], natural hazard[10] and vulnerability data[11] are visualized by means of interactive interfaces (sometimes referred to as called climate services[12]).

Numerous regional and international institutions and agencies have launched web tools concerning climate and climate related data. Although they are still predominantly used by scientists, an increasing number of decision makers and homeowners is seeking access to such tools[13]. For example, the Nature Conservancy organization released the Climate Wizard (www.climatewizard.org) to allow experts and non-experts alike to visualize the impacts of climate change anywhere on Earth. In addition, a range of easy-to-understand climate maps and tools has been released by NOAA (www.climate.gov/maps-data). These examples represent initiatives to design tools which could allow the general public to see, use, and understand data in a user friendly format that was once accessed only by scientists. However, the services differ greatly regarding functionality, design and visualization strategies[14]. Previous tools generally feature solutions typical for geographic visualization (geovisualization) but include various visualization techniques stretching from one-view interfaces to complex visualization systems with coordinated and multiple views[15,16] encompassing several interactive maps and data displays.

Furthermore, despite clearly presenting anticipated effects of climate change, previous tools seldom include interactive information on adaptive measures. Growing concern about climate change and its impacts implies an increased need for measures that could facilitate adaptation to changing natural conditions[17]. Although there are projects reported in the literature where various aspects of visualization of exposure to possible hazards are investigated[18] interactive tools showing direct suggestions are rare. The lack of common visualization strategies among existing interfaces, and the lack of explicit information on adaptation, present challenges for studying the effectiveness of visualization tools for contributing to the understanding of climate change risks and adaptive measures by end-users.

3.2. User-focused studies on tools supporting climate change adaptation

User studies of map-based web interfaces supporting climate change adaptation are scarce and dispersed in various domains. Relevant findings are most often based on feedbacks collected during workshops or software demonstrations. Additionally, user studies generally address experts such as spatial planners and policy makers[12] or emergency managers and land use planners[11], when supporting visual exploration of climate and natural hazard data, rather than laypeople. For instance, in the context of hazard mapping for emergency specialists, Tate et al. gathered reflections on user needs while demonstrating the Integrated Hazards Assessment Tool (IHAT) to county emergency managers and regional planning officials[10]. In turn Battersby et al. investigated a tool for natural hazard education with in-service teachers[19], concluding that data used in a tool should be reliable and consistent, whereas a tool's layout should be designed using cartographic principles.

The lessons learned from the few studies on tools supporting climate change adaptation nevertheless encompass some common suggestions for how to develop these types of services. First, reliable and consistent data content is always a key issue. Second, interactive interfaces should be intuitive, user friendly, and designed according to cartographic principles[2]. If a tool is difficult to learn or overloaded with content and/or interactive functions, users might give up on it and leave the website. Finally, the range of potential user preferences makes it impossible to fulfil all expectations, so it is naïve to believe that a tool can be attractive to everyone. Here, Neset et al. claim[2] that two main challenges facing map-based tools supporting climate change adaptation are to: 1) integrate information on adaptation measures with climate change- and impact-related information, and 2) maintain a balance between representing the inherent complexity and vast information, on one hand, and the fairly broad user profile of most tools, on the other.

4. The VisAdapt tool

The VisAdapt tool (Figure 1) differs from current state-of-the-art visualization tools in the area of climate change and adaptation in that we developed it specifically for non-experts. The interface is structured as a three-step exploration process, going from left to right, by three linked modules: locate → investigate → act. Directing a user's attention by arranging the parts of a visual interface in a sequence of predefined and logical steps is not a novelty in itself in the visualization domain. We often find such functionality implemented in help or tutor visual systems. However, within the VisAdapt tool, such an approach has for the first time been developed to convey the multifaceted information on climate change and adequate adaptation measures, and thus, to support adaptation actions.

Apart from the functionality tailored to meet laypeople's requirements, we prepared the data content on adaptation measures specifically for homeowners. Users can select a certain location or regions in order to, first, discern information about potential climate impacts and risks, and then, to get acquainted with the adaptation measures from national government authorities, research institutes, municipalities and insurance companies in Denmark, Norway and Sweden[5]. This enables the assessment of local vulnerability and reflection of possible adaptation options.

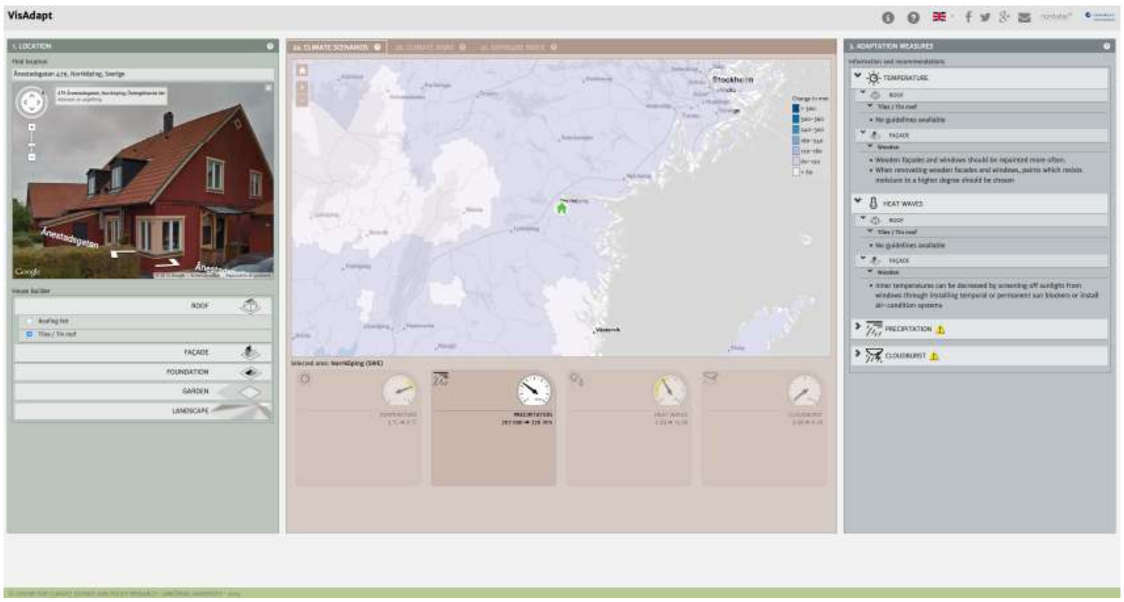


Figure 1: The main layout of the web-based tool VisAdapt consists of three main modules. In the first module (left) a user selects a location and sets specific features of their own house, such as type of facade or topography of the garden. The second module (middle) shows a number of climate scenarios and climate risks as well as exposure indices for the selected region. In the third module (right) information is provided on possible adaptation measures that are of particular relevance to the climate parameters which are expected for the selected region and for the specific house type. All modules are interactively linked so that a user action in one module propagates to the other modules, which update to reflect the change.

Let us illustrate the functionality and utility of VisAdapt by a real user scenario. The user in this example is a Swedish citizen living in the city of Norrköping. The user is generally interested in exploring the effects of climate change in the region. Moreover, due to owning a house with a wooden facade, the user is more specifically interested in future risks associated with possible increase in annual mean precipitation and annual mean temperature.

The first module, entitled ‘Location’, of VisAdapt is shown in Figure 2. Here, the user starts with entering his/her address (A in Figure 2). After providing the information about the location, the user is expected to specify the different features of the house, such as type of roof, having a cellar or not, type of garden etc. (B in Figure 2). At all times it is possible to get further help by clicking on the question mark in the top right corner (C in Figure 2).

Figure 2: The user inputs the location (A) and specifies descriptive features of the house (B). Here, a wooden facade is selected. Clicking on the question mark (C) provides further explanations.

The parameters from the first module are in the second module combined with a multitude of information on climate scenarios, climate risk, as well as exposure indices. The user starts browsing through different climate variables. By a quick look at the 'change gauges' (Figure 3) he/she discovers that the projected change in the annual number of days with a heat wave (yellow arches in Figure 3A and 3B) and the projected change in the annual mean temperature (yellow arch in Figure 3C) are most prominent for the given region. The number of days with a heat wave is projected to increase from 2 to 13, whereas the annual mean temperature is projected to increase from 5 to 8 °C during the coming 40-60 years. Continuing the investigation, the user also finds out that the projected change (increase) in annual precipitation (Figure 4) and the number of cloudburst events is not so significant and will probably not be something that needs to be explicitly considered if renovating the house in the future. Moreover, the user discovers that the gauge hands move (see for example two positions of the same gauge hand shown in Figure 3A and 3B) which implies that there is uncertainty in the projected values.

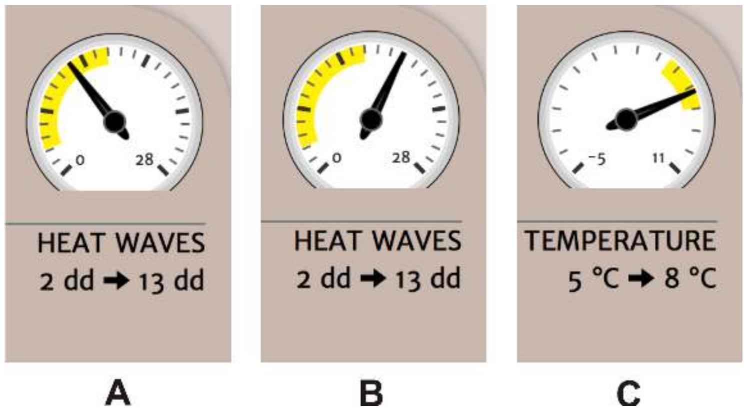
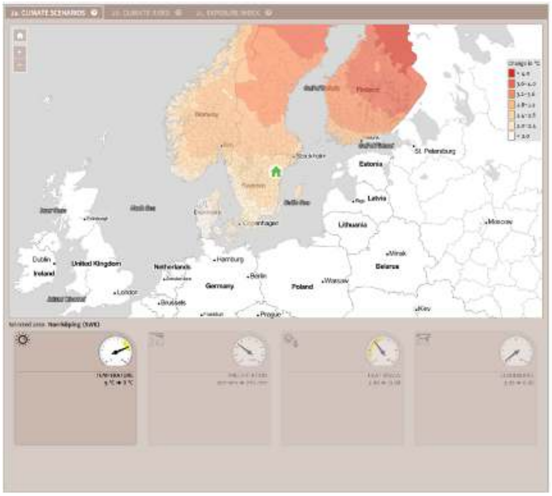


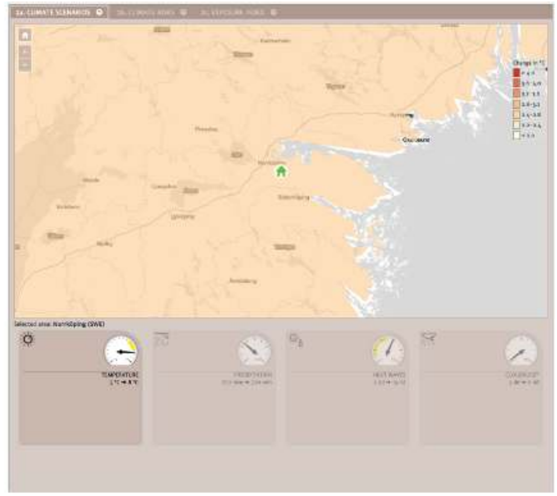
Figure 3: The yellow arches in the change gauges give an overview of the projected changes for a selected region. The movements of the gauge hands indicate the level of uncertainty in the scenario. The change in the annual number of days with a heat wave is for instance projected to increase from 2 to 13 (A, B). However, the gauge hand oscillates to simulate the uncertainty in the data, from the (projected) possible minimum change (A) to the (projected) possible maximum change (B). When it comes to the change in the annual mean temperature (C), it is relatively smaller than the change in the annual number of days with a heat wave.

After getting acquainted with the climate scenarios for the selected location, the user moves on to explore climate risks for flooding and sea level rise (see figure 5) and exposure indices and finds out that according to the current projections there is little to worry about.

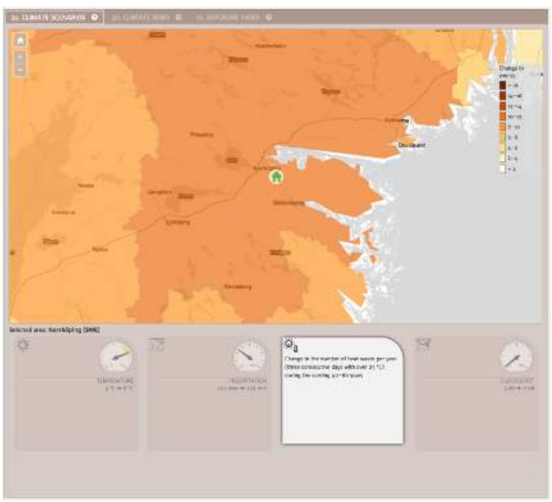
The next and final step for the user is now to obtain information about what adaptation measures can be undertaken. Reading the information provided in module 3 of the user interface (Figure 1), it seems that for the specific location and the house type, the wooden facade is the most vulnerable part to an increase in both annual mean temperature and annual number of days with a heat wave. Hence, the house owner should care which type of paint to used, and consider to repaint more often. VisAdapt also provides the user with some information regarding how to decrease indoor temperatures during the warmest season. With this new information in mind the user feels more aware of recommended adaptation actions and exits the tool.



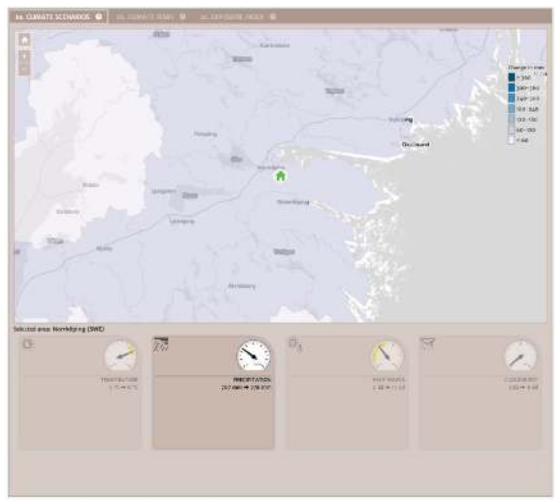
A Temperature change for the southern part of the Nordic countries.



B Temperature change for the region of Norrköping in focus.



C Change in the number of heat waves.



D Change in precipitation.

Figure 4: Projected changes in different climate variables for the selected location in Norrköping, Sweden during the forthcoming 40-60 years. While the projected changes (increase) in the annual mean temperature (A, B) and the annual number of days with a heat wave (C) are of concern for the user, the increases in the annual mean precipitation (D) and the annual number of cloudbursts (not illustrated here) seem unlikely to have any major effect on the house in the coming years.

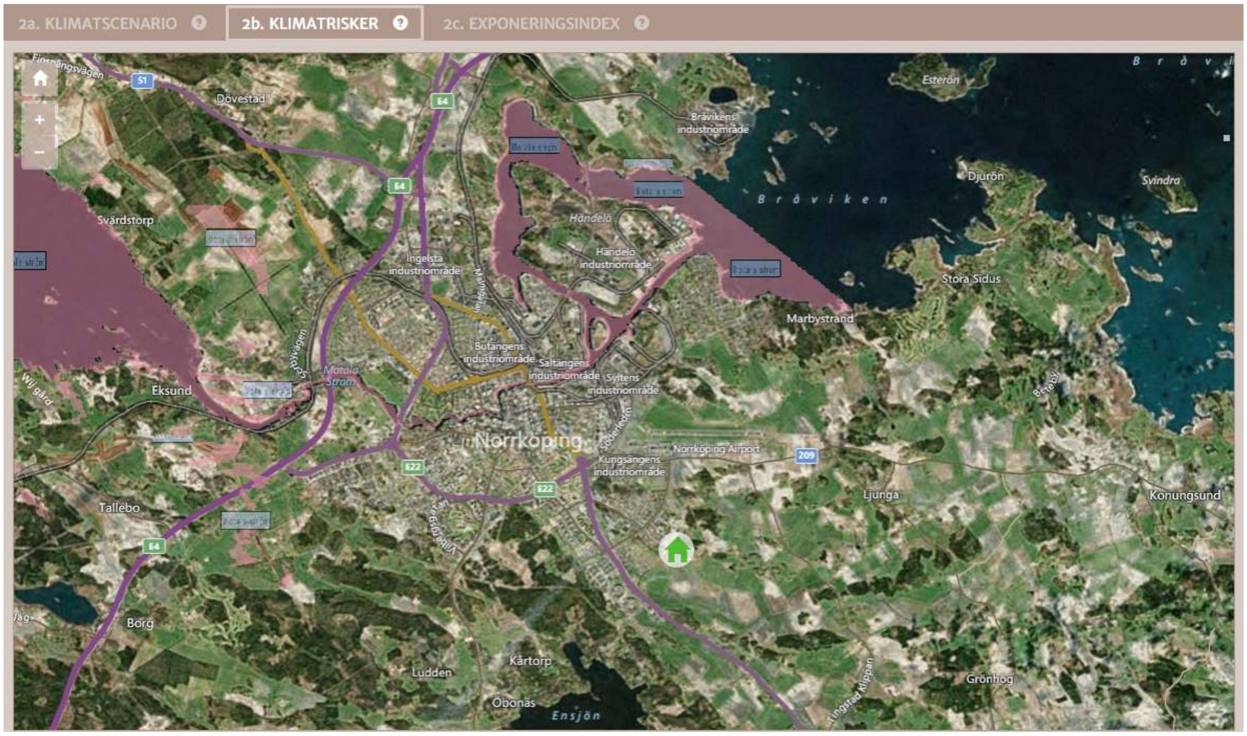


Figure 5: Looking at the risk area for a '*100 year flood*' (the statistical measure for areas prone to flooding once in 100 years) indicates that there is nothing to worry about for the specific geographic location of the user's house.

5. User-centered design through continuous evaluation

Although the VisAdapt tool exhibits a straightforward visual interface design based on common and broadly known solutions such as choropleth mapping technique, tabbed document interface (tabs), or searching mechanism powered by Google Maps API, the research and development process that led to the final layout was challenging, extensive and multistage. Choropleth mapping techniques were chosen over layering techniques since it allows for easier interaction with regions on the map. In order to avoid major design mistakes and shortcomings regarding the tool's content, the visual representations and the tool's overall functionality, as well as to ensure that users' requirements were fulfilled at each step of the tool's development, a continuous evaluation was accompanying the entire design process. Therefore, we are using the term user-centred design when describing our efforts. In this section, we discuss the rich experience gathered during the design and development work and the whole design process that led to the VisAdapt visual interface.

We designed and developed VisAdapt iteratively and collaboratively, over the course of three years, using the expertise of visualization and climate change researchers and of specialists from Nordic insurance companies. Moreover, we engaged potential end users at several stages of the development process. Altogether four different parties: (1) end users, (2) insurance industry representatives, (3) climate change experts, and (4) information visualization experts along with developers have participated in the development process and contributed to the final software design. Table 1 gives an overview of the engaged collaborative parties.

Participating parties	**Type of participation**	**Type of stakeholders**
End-users	Single person test sessions	6 homeowners from Norrköping
	Group test-sessions	35 homeowners from Aarhus, Norrköping and Trondheim
Insurance industry representatives	Recurring workshops	Representatives from 4 Nordic-wide insurance companies
	Workshop	Representatives from 4 Nordic national insurance organisations
Climate change experts	Active involvement in all development stages	Researchers from The Swedish Meteorological and Hydrological Institute, SINTEF building research and Linköping University
Information visualization experts	Active involvement in all development stages	Researchers from Linköping University and Norwegian University of Science and Technology

Table 1: Involved collaborative development parties.

The joint development process facilitated a good understanding of what is required and useful in terms of contents and design for the identified target audience. Figure 6 illustrates the milestones of the prototyping along with the information on the contribution of the four parties. In this case, the term milestone does not refer to any software development method known from software engineering (e.g. waterfall or agile software development) but is linked with the tool's collaborative design and development where the parties played particular roles and had specific contributions.

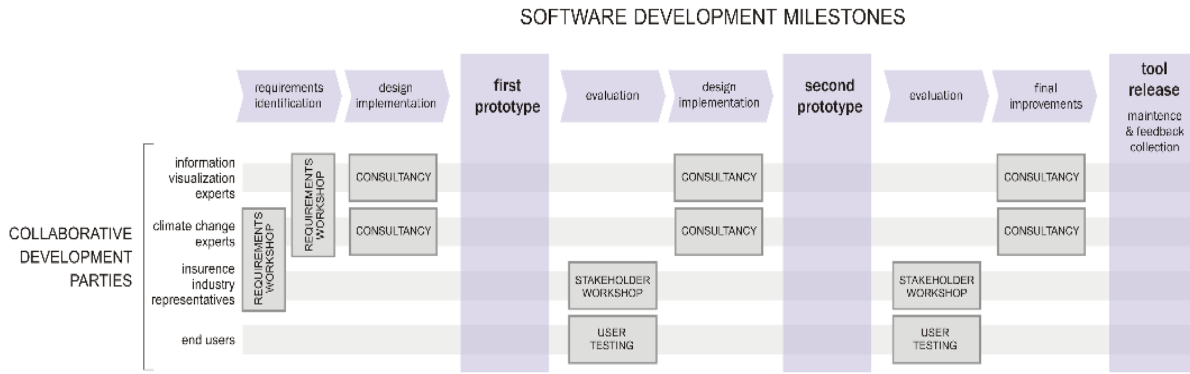


Figure 6: The detailed workflow of the development process.

The development process, and thus the prototyping, has been preceded by analyzing the role of the tool for the target audience – Nordic homeowners. At an early pre-development stage, climate change experts had requirement-focused workshops with insurance industry representatives. Here the idea was born that the tool should apply various visualization and interaction techniques to facilitate individuals' capacity to adapt to climate variability and change through learning and exploration of information on expected climate and weather related risks and adaptive measures. The active involvement of the insurance industry representatives provided an insider perspective of the problems that their customers (homeowners) have faced in trying to make sense of climate change information which facilitated a specification of information contents and the general visualization design. Through their data on claims payments, the insurance companies also provided valuable information on what natural hazards currently are generating most damage to residential buildings in the region. We used this information to inform the collection of adaptation guidelines and to create a list of specifications for the general layout of the tool. To make global changes tangible for homeowners, a feature focusing the user's attention to impacts in the users' local area was one of these specifications, which informed the incorporation of the Google Street View component.

We established the first design settings through a two-day workshop involving the authors as well as several other specialists on climate change and information visualization. The essential decision undertaken was to develop the tool as an application with coordinated and multiple views[15,16] to create a logical flow of information as outlined in the requirement-focused workshops. Furthermore, we discussed the preliminary assumptions for a suitable technology and decided to develop the tool as web application based on JavaScript open source APIs such as OpenLayers.js and D3.js. The workshop was followed by the design and prototyping (implementation) that led to the first prototype; designed in accordance with the coordinated and linked views approach and featuring a visual interface consisting of five views, as illustrated in Figure 7.

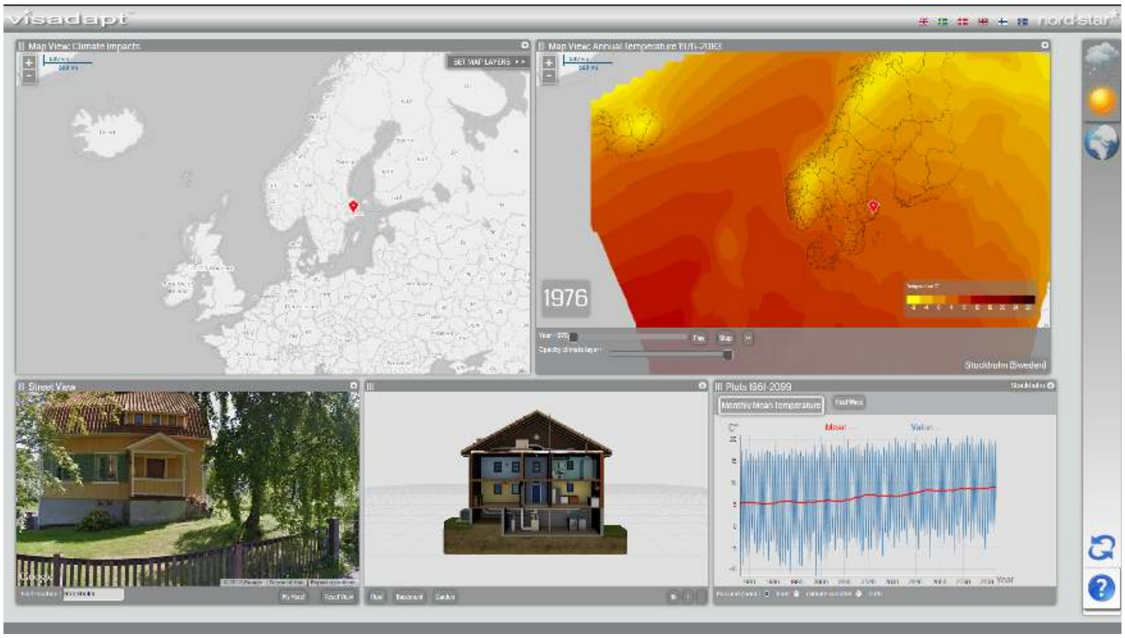


Figure 7: The first prototype of VisAdapt employed a coordinated and multiple views setup.

The first prototype was assessed through two forms of deliberation: 1) workshops were held with representatives from insurance companies to assess the usefulness of the information that was integrated in the tool for the purpose of identifying risks to residential buildings, and 2) test-sessions using the think-aloud evaluation method were conducted with six potential end-users in Norrköping. The feedback from these assessments all revealed that the interface of the tool was somewhat illogical, that the line graphs provided were difficult to interpret and interact with and that information on adaptation actions was hard to find, being presented first after clicking on specific house parts in the generic house (figure 7). The think-aloud evaluations provided a fruitful source of information on how the design of the tool were understood, and revealed a lack of guidance on what features should be viewed first in order to understand the other features. They also revealed that the generic 3D house feature was creating confusion since several users thought it were linked to their own house shown in the Google Street View feature and then not matching its characteristics (i.e. type of roof, number of floors, type of foundation, etc.).

To adjust the above shortcomings, the results of these stakeholder and end-user assessments suggested that individual decision-making processes of the intended end-users should guide the visual interface more explicitly, following a clear line of thought. In order to avoid confusion, all information should also align with this structure, demanding the removal of all excess data in the tool and more explicitly highlight the interactive components. Based on the results from these deliberations, a typical user scenario was defined with the key tasks that the tool should support. Three steps constituted the defined user scenario: (1) locate your house (type in your address) and provide the system with its characteristics (e.g. type of walls and roof), (2) use interactive map displays in order to investigate your place's vulnerability towards various climate and climate-related parameters, and finally (3) get acquainted with the adaptation measures and act. The second prototype was then developed following the scenario based design[20]. Here the use of the tool was concretely described by the three-step approach (Figure 1). Furthermore, during this design process – as stressed by the insurance representatives – it was decided to make the adaptation guidelines panel more visible and to develop a direct interactivity with the information by letting the user type in address and house features. This interaction was created by developing the house builder interface (figure 2, section A), where the user selects materials/features of his/her house, which directly correspond to what guidelines are shown. The guidelines are also visually ranked according to what climatic trends are expected to be most dominant in the region of the selected address (annual temperature, frequency of heat waves, annual precipitation and frequency of cloudburst). This function created a direct and visible interactivity where the list of adaptation guidelines is changing when typing in a new address or selecting different house material/features without any time lags, as demanded by both end-users and insurance representatives.

The second prototype was assessed through a workshop with the insurance representatives as well as representatives from four Nordic branch organizations of the insurance sector and a series of 16 hands-on test-sessions with 35 homeowners divided into groups of 2-3 persons in Aarhus (Denmark), Norrköping (Sweden) and Trondheim (Norway). The representatives of the insurance sector were generally positive towards the new design and interactivity but asked for some continuous explanation (e.g. an explanatory film) to guide users through the various steps. In response to this request, we created a tutorial slide show before the group test-sessions. This approach was chosen instead of the proposed film since each slide could be linked directly to the specific steps in the tool more easily using clickable question marks (figure 2, section C). The group test-sessions revealed that the potential end-users generally understood the three-step approach, including the slide show. However, several users argued that the guidelines were sometimes contradictory, that the level of auto-zooming was often too zoomed in and that the gauges (figure 3) provided valuable information but were hard to interpret. Some users also argued that too much information was shown while others would have liked to see more information. A frequently raised issue was also that the tool created engagement and a will to learn more, which also was obvious judging from the intense discussion on anticipated local impacts and the appropriateness of the various guidelines.

As a response to the input from the group test-sessions some last improvement of the tool was made before the official launch in November 2014. First, a consultancy specializing in climate change and weather impacts on buildings was assigned to examine and further develop the adaptation guidelines to make them less contradictory. Second, the auto-zooming was further developed to make the colours of the climate change maps appear more clearly. Third, related to the amount of information, we updated the tutorial to present the information in the various steps in a way that describes more clearly the subsequent actions users have to execute in order to successfully interact with the system. Fourth, we made the details of the gauges (figure 3) more visible and understandable by increasing the size of the numbers and including an explanatory text.

The gauges, nevertheless, stood out as the most problematic feature for homeowners to understand in the VisAdapt tool and still remains a challenge in future developments. Inputs from the end-user evaluations revealed that several users generally wanted more information on how to make sense of the numbers presented. To some extent, we managed to solve this by presenting a short text on how to interpret the scale and anticipated changes on the backside of the flipping tile and in the tutorial slide-show which is shown when clicking on the question mark available at each step of the tool (C in Figure 2). The uncertainty visualization provided through the gauges (i.e. the movements of the gauge hands which indicate the level of uncertainty in the scenario data) was also considered as somewhat hard to understand by the users but were, when explained, seen providing valuable information. Except presenting the functionality of the movement of the gauge hands in the slide show, we have yet not found a more intuitive way of transferring this information. However, as mentioned by some of the users in the evaluations, the movement triggered interest to learn why the gauge hands moved which made them click on the question mark. How to visualize uncertainty in the climate data in a more intuitive way thus still remain a challenge in future research.

6. Implementation details

In this section we briefly present the technical implementation of VisAdapt. We have developed the tool based on a single page web application paradigm using the open source APIs AngularJS, OpenLayers, D3, and Bootstrap. The structure of the application is based on the model view controller based framework AngularJS, which is used to set up a single page web application. To make the application responsive and capable to work on several devices, we use a set of design templates such as tabs or accordion, from the bootstrap library. For displaying maps and geo-referenced data the OpenLayers library has been used which provides functions to display map tiles and data layers on a HTML canvas. The JavaScript library D3 for interactive data driven visualization has in turn been used to implement the gauge components.

7. Discussions and conclusions

The development of VisAdapt turned out to be more challenging than expected but has at the same time given the design and development team valuable insights regarding the visualization design and knowledge about how interactive visualization can be used to facilitate data exploration for laypeople. Although we designed VisAdapt for Nordic homeowners, the insights gained from the development process and the lessons learned from the project including the extensive evaluation process could likely be valuable to researchers in a wide area of application domains.

7.1. Lessons learned

The main lesson learned from the software development exercise happened after the first prototype design when decided which changes we should implement for VisAdapt. We developed the he first prototype (Figure 7) using a coordinated and multiple views setup, with no particular logic regarding the way that views are distributed across the interface. However, the user-centred design helped us avoid a design mistake as the empirical study revealed that such approach is not necessarily effective if the target audience are lay users. In order to facilitate for users to understand the flow of information (from general anticipated changes to specific climate risks to adaptation measures) we redeveloped the tool to more specifically steer users' interaction as demanded by test-users. In the second prototype (Figure 1) we reduced the number of parts in its visual interface and arranged them in a sequence of predefined and logical steps which are to direct a user's attention. Though this approach is not a novelty in itself in the visualization domain, through the VisAdapt tool such an approach has for the first time been developed to convey the multifaceted spatial data on climate change risks and adaptation measures. Our research reveal that it is important that tools such as VisAdapt is directing users' attention directly to information that is relevant for the users' local area and house type to create engagement. This makes it possible to only present information that is directly important for the specific user which seem to make people more engaged and interested in exploring the contents of the tool.

With the above findings, the lesson learned regarding the visualization design is twofold. First, if one wants to design for lay people, a complex visual interface in general and a coordinated and multiple views tool in particular, directing a user's attention to the order in which the data should be analysed within the interface, should be considered. Second, due to the user-centred design approach VisAdapt has been successfully designed and developed as a coordinated and multiple views tool for non-experts. To our knowledge, it is uncommon to have such a tool dedicated for the general public. Hence, the layout settings consisting of three visual step-wise components distributed horizontally as well as the overall tool's visual design can be valuable as a starting point for researchers and developers who plan to develop a coordinated and multiple views tool for the general public too.

Related to the above, a recurring challenge throughout the project was the trade-off between creating a user-friendly interface and integrating relevant climate data. For example, each time we included additional scenarios, the number of potential combinations that could be interacted with and visualized increased exponentially, which in turn made the user interface perceived as too complicated. After several tries and evaluations we therefore included only one climate scenario, describing the “worst case” in terms of increasing global emission of greenhouse gases, and only one period, presenting changes over a relatively short time perspective. An important lesson learned regarding the user interface was that most end users still regarded it as too complex. One obvious problem with only using one climate scenario is however that the data may appear as less complex than it actually is which decreases transparency, as pointed out in a few evaluations. One possible way forward discussed could be to use a default setting for climate scenario and time period which could be opened-up for interested users. When tested in earlier versions of the tool, though, this seemed to direct attention away from the important part of the tool presenting possible adaptation measures. An idea for future development of VisAdapt is to include further data exploration as an option presented after the user have familiarised him/her selves with the presented adaptation measures, How this should be done still remain an open question.

It cannot be stressed enough how important it is to include end users in the development process, and in particular in the initial design phase. When creating the user interface of VisAdapt it became obvious that we had to get a comprehensive understanding of our potential end users’ individual decision-making processes (i.e. how users perceive the management of his/her own house) to be able to understand how they interpret the information provided in the tool. Here, the cooperation with a partner that knew the target audience (the insurance companies) facilitated a good initial understanding of these decision-making processes. Involving such a cooperating partner in the initial development steps of any visualization tool can potentially save a lot of time and efforts in later development stages.

Another important lesson learned from the many evaluation sessions is that familiarity increases interest to explore local impacts and possible adaptive action. We achieved familiarity in two ways: 1) the Google street view component created a sense of local familiarity and made global changes appear as tangible on the local level, which was important in order to create engagement, and 2) it was clear that providing the tool in the users’ native language and avoiding technical terms increased the willingness to use the tool.

Making users aware of the uncertainty in the data was another challenge. This is recognized as a general visualization problem and in our case it is important to communicate that the data does not represent actual “facts” but are projections distorted by uncertainty. VisAdapt shows data uncertainty through different animated “gauges”. Despite our best efforts to make them as easy to interpret as possible, they have been evaluated as hard to interpret by several test users. However, after explanations these were considered as meaningful and valuable. Our efforts to visualize uncertainty by moving hands on these gauges provide a method for visualizing uncertainty in climate change data. However, how to take this knowledge further remains an important question for future research.

7.2. Future challenges

This study points towards several challenges and improvements that are important to address in future research. For instance, adding more specific and easy to use adaptation measures would make the tool even more relevant to the end-users. This would, however, demand that such information is developed and composed specifically for the tool which is very time-consuming and expensive.

It would further be interesting to extend the VisAdapt tool with more advanced functionality. This can potentially allow simultaneous representation of multiple scenarios, i.e., multivariate data as presented above, which could be represented using many of the existing advanced visualization techniques[21]. Of particular interest is to investigate the use of 2D and 3D parallel coordinates[22,23]. Adding this type of functionality could attract new user groups such as domain experts, and professional analysts within the insurance and climate change sectors. To make visualization tools directed to lay people more useful also for expert audiences without losing the easy-to-follow logic of the tool is a challenging yet important future research task.

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Sidebar: Climate change, risk and exposure data and adaptation measures

VisAdapt builds on several data sources as listed below.

1. The climate scenario data is based on regional downscaled climate change scenarios provided by the Swedish Meteorological and Hydrological Institute (SMHI) (http://www.smhi.se/klimatdata/framtidens-klimat/ladda-ner-scenariodata). The selected parameters present anticipated change in annual average temperature and precipitation as well as the change in the number of events of heat waves (3 consecutive days over 25 degrees) and cloudburst (20 mm hourly) for anticipated climate change in the period 2051-2070. The selected climate scenario is the highest of the AR5 scenarios, where global emissions of greenhouse gases continue to increase during this century (RCP 8.5).

2. The risk maps were compiled from publically available databases, provided through Scandinavian sector authorities.

3. The Exposure Indices were provided by the NORD-STAR research partners at the Norwegian University for Science and Technology (NTNU) in Trondheim. For more information regarding the data please visit:

http://setebos.svt.ntnu.no/viewexposed/learn_about_vul/

4. The adaptation guidelines and measures were collected from Scandinavian authorities, municipalities and insurance companies. For a full compilation and references, see Glaas et al., Doi:10.1016/j.uclim.2015.07.003, 2015.