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Conceptional Design of an Application for Guidance in the Energy-based Refurbishment of Residential Buildings

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1. Introduction

In recent years, climate warming has become an increasingly important topic in Germany. Individuals as well as politicians are looking for ways to decrease energy consumption and carbon emissions. The refurbishment of buildings is an effective way to do this. In the European Union, buildings account for about 40 % of heat demand, worldwide for 32 % [21]. In Germany, roughly 40 % of greenhouse gas emissions come from buildings [10]. Thereby, the variety of usage forms leads to very different amounts of energy consumption between individual buildings, as well as different measures for energetic renovation [16]. Irrespective thereof, the potential for refurbishment is generally high, as more than 80 % of buildings in Europe were built before 1990 [26]. On average, European residential buildings consume 150 to 230 kWh/m^2 energy per year, while a well-insulated low-energy building only requires 60 to 80 kWh/m^2. However, homeowners are not properly informed on how they can refurbish their house and their decisions can be distorted by various conditions. For example, small investments with short payback time appear very attractive but do not necessarily yield the greatest benefit. More costly investments often reduce emissions more effectively and lead to greater financial savings in the long run [38]. Besides, lays are often lacking the knowledge about potential measures to begin with.

The internet offers many sources for house owners to inform themselves about their options and the procedure of a refurbishment, but they usually remain quite vague and general. In order to get to know the actual costs of a refurbishment in an individual case, house owners need to contact a craftsman directly and request an offer. However, this requires to know which refurbishment should be done and which craftsman is equipped to conduct it. Retrieving all this information takes a lot of effort and time, which many homeowners do not have or are reluctant to invest. To solve this problem, the information should be bundled in a tool that is easily accessible for anyone. Although several tools exist that can help to assess houses and determine suitable refurbishment measures, they are usually targeted to experts in the area. Section 1.1 will elaborate on some of these tools, which are hardly usable for lays. In this thesis, a mobile application is designed, that is specifically targeted to house owners without any prior knowledge about construction work or refurbishment measures. This app should be freely accessible in App Stores and easily usable by lays. It integrates various simulations to assess the current state of the user's house and compute suitable refurbishment measures for the user's house specifically, based on simple parameters that need to be entered by the user. Recommended measures are therein listed in a concise and comparable way, such that users can make an informed decision about what they want to do. The application is conceived to immediately suggest craftsmen that offer the services required for the refurbishment at hand, thus enabling the user to contact them directly, while providing the expert with all the relevant house data to speed up the process. Additionally, users are informed about possibilities to receive government funding.

Overall, the application is conceptualized to guide users seamlessly through the whole procedure of refurbishing their house: From assessing the status quo, over determining suitable measures and comparing their costs and benefits, to receiving potential funding and consulting a craftsman to complete the project. This bundling significantly facilitates the process and is intended to motivate house owners for the optimization of their house.

1.1. Related work

There is a lack of tools focusing on the planning of building renovations, especially simple ones [16]. Instead, existing systems often support with design decisions or provide sustainability certifications for buildings [23]. In the following, various tools for any kind of building evaluation are presented.
The Excel-based tool *EnerCalC* [1] is meant to facilitate the assessment of energy performance for non-residential buildings. Rather than during the planning of renovations, it is to be used in the early design phase of buildings. Thereby it follows DIN V 18599 but makes several approximations to reduce the effort of data collection, so it should only be used for estimations [10]. Nevertheless, a large amount of input is necessary as can be seen in Figure 1. The image shows only a part of the input fields but gives an impression of the complexity that remains. Among the input data, there is also a

[1]https://ingefo.de/Werkzeuge/EnerCalC/

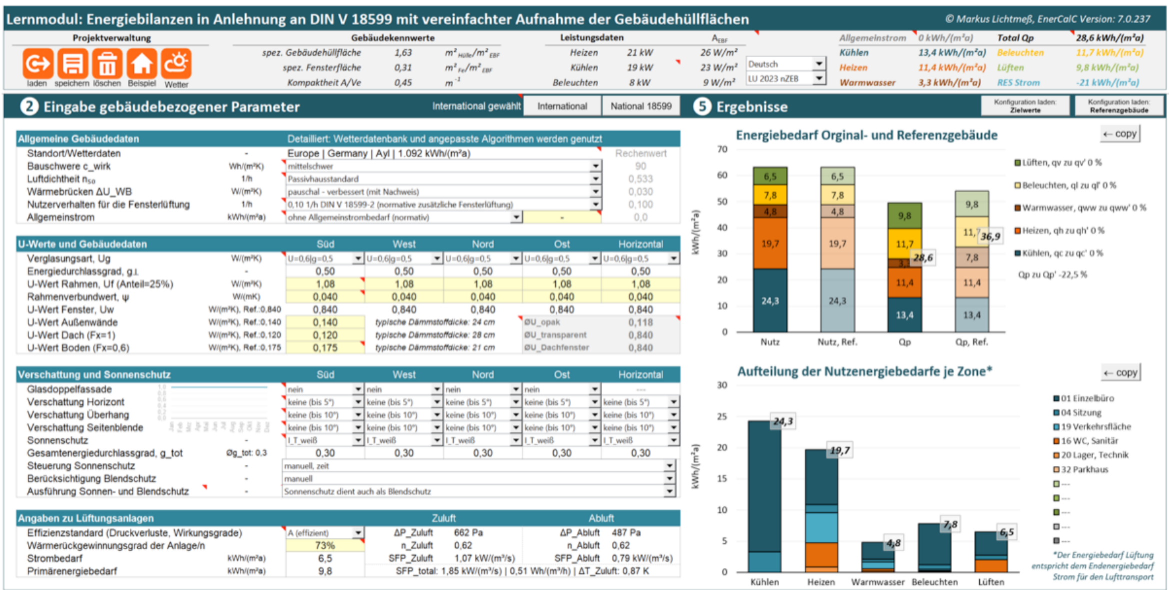


Figure 1: This is an example screen shot of the excel-based tool *EnerCalC*. The interface contains four tables for data input on the left and graphs for the presentation of computation results on the right. There is a lot of information on one screen and it appears cluttered, although the input data is separated thematically. There are many input fields with technical terms and rarely used units, which make it hard for inexperienced users to understand them.
(source: https://ingefo.de/Werkzeuge/EnerCalC/)

lot of technical information that private citizens are usually unaware of, such as the construction weight c_{wirk}. In many places, a drop-down menu gives a set of selectable options, but users unfamiliar with building construction can only guess the correct value. For this reason, the tool should be used by experts, e.g., energy consultants or heating engineers. Their technical knowledge is necessary to be able to easily collect all data in the tables and make use of the result plots showing the heat and energy demand of the planned building.
The *ASCOT calculator* provides more suggestive information as it enables users to compare the ecological benefits of specific renovation measures on an existing building. With the help of predefined cost data and by computing the resulting energy savings, the most beneficial measures can be chosen after the current energy consumption is assessed. The tool is based on ISO 12790 and utilizes adjustable data pools, i.e., parameters like U-values and air-tightness are estimated with standardized values but can be modified [10]. This way, users can get results without knowing the exact technical characteristics of the building.
In the course of the *HoEff-CIM*-project, Dotzler et al. created a decision-making methodology for building renovation. This methodology includes the assessment of existing building stocks as well as the planning of their renovation and aims to assist regional governments in local energy and climate policy decisions, including the planning of energy concepts for the municipal sectors. It implements a *Quick Check Tool (QCT)*, installable on mobile devices, to guide also inexperienced users through the inspection of buildings. Basic information such as location, age, construction type and architecture of the building, are saved in this tool before more detailed and technical data is collected on-site. Each room is classified into one of 16 energy classes, which were previously defined based on an analysis of 1600 different usage scenarios. With the *reference room method (RRM)*, energy demands and potential renovation measures are determined based on the energy class and other collected data. The results for single rooms are subsequently extrapolated for the whole building. This way, the simulation process can be significantly accelerated. The open source building simulation software *EnergyPlus* of the *U.S. Department of Energy (DOE)* is used for a performance simulation and all results are condensed into an energy master plan, which visualizes various energy efficiency scenarios and provides steps for a strategic renovation. With this plan, owners of large building stocks can see which buildings have the highest potential for renovation [10].
In 1997, the decision aid tool *EPIQR* [2] has been proposed at the *International Conference for buildings and the environment* in France. It was meant to facilitate the rapid collection of data about a residential building in order to help architects, engineers or technicians of the building sector to get an overview of all relevant parameters. While it does not require any specialization in investigation or analysis methods [18], some expertise in building refurbishment is necessary, as it only assists in decisions. To this end, the building's deterioration, energy performance, indoor environment quality and compliance with standards and regulations are diagnosed. The building is decomposed

[2] https://www.calcon.de/epiqr/

into elements such as windows, facade, boiler et cetera, and the user specifies the type and deterioration state for each of these elements. About 500 photos and sketches as well as detailed descriptions give an indication for the appraisal. Different modules allow working in different degrees of detail and in the end, the expert user can build various refurbishment scenarios and calculate their costs and potential savings, financially as well as energetically. The deterioration state and refurbishment costs for all building elements are visualized in a radar graph. The user can select or deselect any number of the recommended actions to see the effects in the graph and decide which refurbishment steps they want to pursue based on the available budget. For each element, there is also a detailed overview of its state of deterioration, remaining life span, national standards and relevant complaints of building occupants. With these options, the expert can conceptualize a refurbishment plan to discuss with the owner. In an iterative process, they decide on a procedure, where the program computes more accurate cost estimates and the expert can give their own estimates. A first estimation of refurbishment costs can be acquired in about four hours, but an all-encompassing assessment of the whole project needs at least two to four working days [14]. The tool has been commercialized and is now mainly used by private investors [10], but also as a pedagogical instrument to teach building refurbishment at the *Department of Architecture* of the *Federal Institute of Technology* in Lausanne. The software runs on PCs with Windows 95/NT4 and has three extensions, which are focused on different building types: *TOBUS* focuses on office buildings [14], *XENIOS* on hotels, and *INVESTIMMO* is targeted to owners of multiple apartment buildings. These cases have different requirements, for example, because hotels often underlie seasonal energy loads. In addition to the regular functionalities provided by *EPIQR*, *XENIOS* investigates how to improve indoor air quality, save resources and reduce waste [2]. In contrast, *INVESTIMMO* aids in prioritizing and timing the refurbishments of single buildings within a stock. It utilizes *EPIQR* for collection of the house data but adds further functionalities such that many external criteria can be taken into account. Those include for example the housing market, tenant expectations, building aesthetics, historical or cultural value and the environmental impact of the refurbishment measures themselves in terms of energy and resource consumption [2].
The software company *ENVISYS* [3] developed a multilayered tool called EVEBI [4], which assists in many tasks around the energetic and financial evaluation of a residential building. The basic version offers all functionalities necessary for the creation of energy certificates and a complete energy consultation according to DIN V 18599, but it can be individually extended with various modules for many other tasks. These include among others a simplified market value computation, elaboration of a ventilation system, yield calculation of photovoltaic (PV) systems and the import of existing data files. With only a few inputs that can be quickly acquired, the tool provides an initial consultation. Upon switching to the extended evaluation, the previous data is adopted to avoid double entries. In addition to the planning of renovations, the

[3]https://www.envisys.de/startseite/
[4]https://www.envisys.de/energieberatersoftware-evebi/

tool is suited to assist in the design of a new construction and thereby helps to conform to all mandatory characteristics of the *Gebäudeenergiegesetz (GEG)*, e.g., owning summer heat protection. From this setting it is also possible to switch to a renovation consultation without any problems. *EVEBI* can automatically generate possible packages of actions to achieve a standard of the user's choice, i.e., for example, the efficiency house standard of the *Kreditanstalt für Wiederaufbau (KfW)* or the passive house standard. These packages are immediately updated in case of changes in the current situation and examined for funding opportunities by the KfW as well as by the *Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA)*. In this examination, the tool takes all grants that were paid for previous measures into account, determines different variants such as funding a package of measures or only a single measure, and provides a concise presentation of the results. The complete funding report can be directly imported to the online portal of the *KfW*. *EVEBI Pro* extends the basic version for usage on non-residential buildings and provides additional functionalities such as a model for building zones, lighting evaluations and a concise presentation of interme-

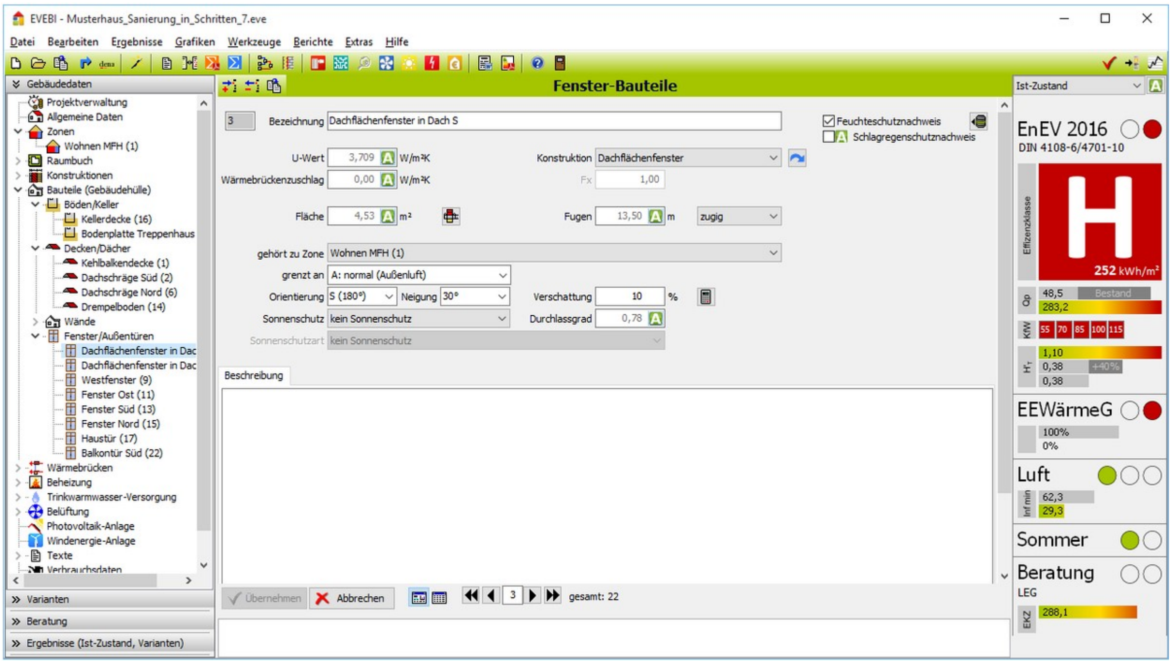


Figure 2: This image shows the interface of the software tool *EVEBI* during the data acquisition for a single family house. On the left, components of the building can be selected, whose detailed characteristics can then be entered in the center panel. Users can also select to display current recommendations or computation results regarding the current condition of the building. In a panel on the right, the energy efficiency class and other key data is displayed in short form. Overall, the tool provides a large amount of functionalities, which can appear cluttered. As the interface contains little to no explanation of the components or displayed data, the usage requires some expertise on the possibilities of the tools itself but also on building renovation in general. (source: https://www.envisys.de/energieberatersoftware-evebi/)

diate results. Both tools can be bought as desktop applications and are continuously improved and adapted to current standards. The software is certified to follow the DIN V 18599 standard and gets used in educational facilities. Teachers there can improve their knowledge in seminars, that are regularly offered by the software company. Although the software provides support in multiple ways such as a digital assistant leading through the data acquisition, automatic inscription of standard or computed values and plausibility checks, it requires some expertise in building renovation or planning and is thus targeted to architects, engineers and energy consultants. Figure 2 shows a screenshot of the basic version during data acquisition. A roof window as a component of the building envelope is currently selected, such that its parameters can be modified in the center panel. Presumably, the green "A" in some of the input fields indicates an automatic completion of this field, which facilitates the data collection. Note however, that there are no further explanations on any of the input fields. An average owner of a residential building without renovation experience is unlikely to be familiar with terms such as U-value or thermal bridge surcharge. Due to the automatic completion they might still be able to generate some results, but the mass of unknown terms and information has probably a tiring and discouraging effect on inexperienced users.

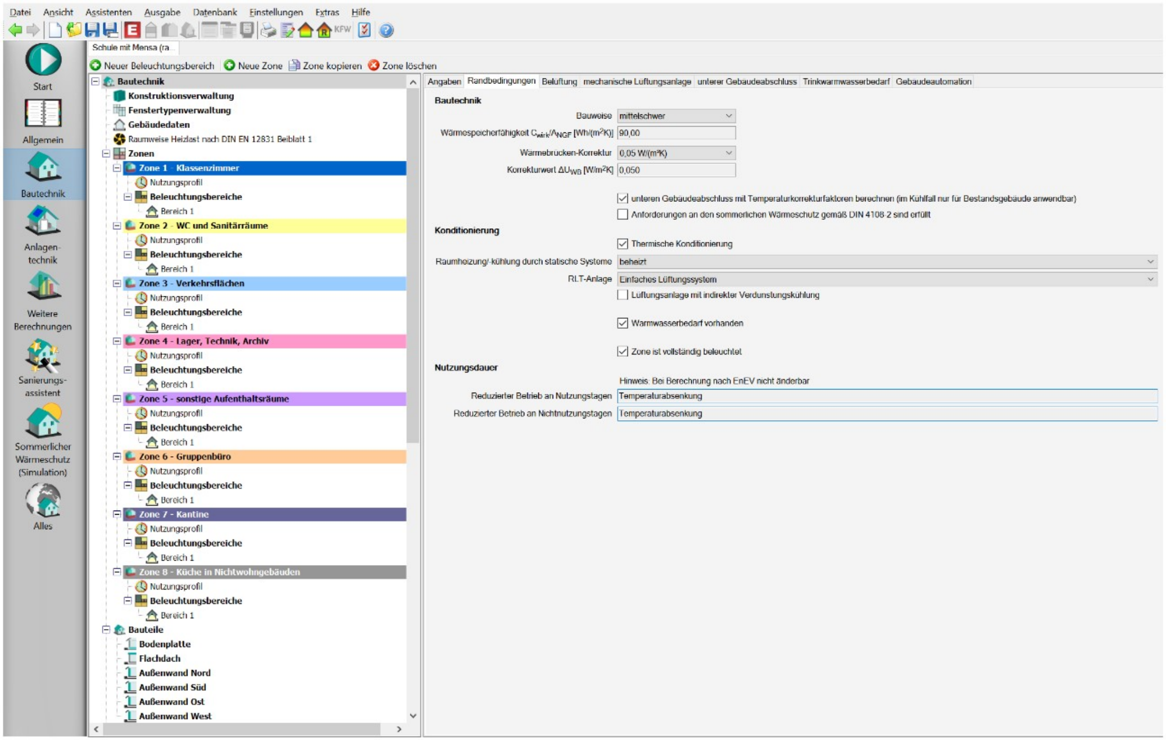


Figure 3: This is the interface of *ZUB Helena*. It consists of a center panel for the input of parameters as well as the display of computation results, and a navigation panel on the left, where individual components and other menus can be selected.
(source: https://www.zub-systems.de/de/produkte/helena)

Similarly, *ZUB Systems* [5] offers a complete energy consultation in their software *ZUB Helena*. It includes an individual refurbishment roadmap, the creation of an energy certificate, and simplified procedures for the computation of heat demand and an assessment of the ventilation system. With four additional modules, the software can be extended for the evaluation of summer heat protection, detailed computations for heat demand and the ventilation system as well as a life cycle analysis. Furthermore, *ZUB E-CAD 4 Pro* facilitates the acquisition of data with a three-dimensional representation of the building, such that users can get a better overview of all components and edit specific data more easily. In the "Ultra" version, ZUB Helena and its extension modules can also be applied to non-residential buildings. Additionally, the company offers stand-alone tools for the computation of thermal bridges, the evaluation of moisture behavior and the thermal calculation of technical insulation. The latter is not specified to buildings but can also be applied in operating technology and shipbuilding.
Figure 3 shows the user interface of *ZUB Helena*. It generally resembles *EVEBI* (cf Figure 2), as it also contains a center panel and a panel on the left for navigation, but it misses the overview panel for results on the right as well as the indications of autocompletion. Another significant difference is the second navigation panel on the right edge, which separates the navigation between different components of the tool more clearly from the navigation between building components. This makes it easier for the user to keep the overview of all functionalities of the tool, but the tab titles might be obscure for users without a deeper understanding of buildings or their refurbishment. The input fields in the center panel are also labeled with technical terms without any explanation.
ZVPlan [6] is a software project constructed by a group of four initiators and three companies. Functionalities are among others the computation of the heat demand, the corresponding design of radiators and underfloor heating and hydraulic balancing. The Pro version extends the tool to work with floor plans and lifts the limit in project size, such that buildings with more than four floors and over 100 rooms can be evaluated. The tool is specifically designed for an easy and quick data acquisition and also includes a 3D representation to this end. Nevertheless, it is targeted to experts and technical terms are not explained in the user interface. An exemplary screenshot can be seen in Figure 4.
Heizreport is a German website, where house owners, technicians or renovation planners can enter information about a building to compute whether it is suitable for a heat pump. This includes an assessment of the current heat demand as well as an evaluation of radiators, heating surfaces and hydraulic balancing. The procedure follows DIN EN 12831 and is simplified to be usable without any expertise. According to the advertisement, the data of a 180 m^2 building can be acquired within an hour and the main results of the computation are immediately accessible as PDF. These include the overall heat demand of the building, highest, lowest and mean specific heat demand for individual rooms and an overview of how many radiators must be replaced

[5] https://www.zub-systems.de/de
[6] https://www.zvplan.de/

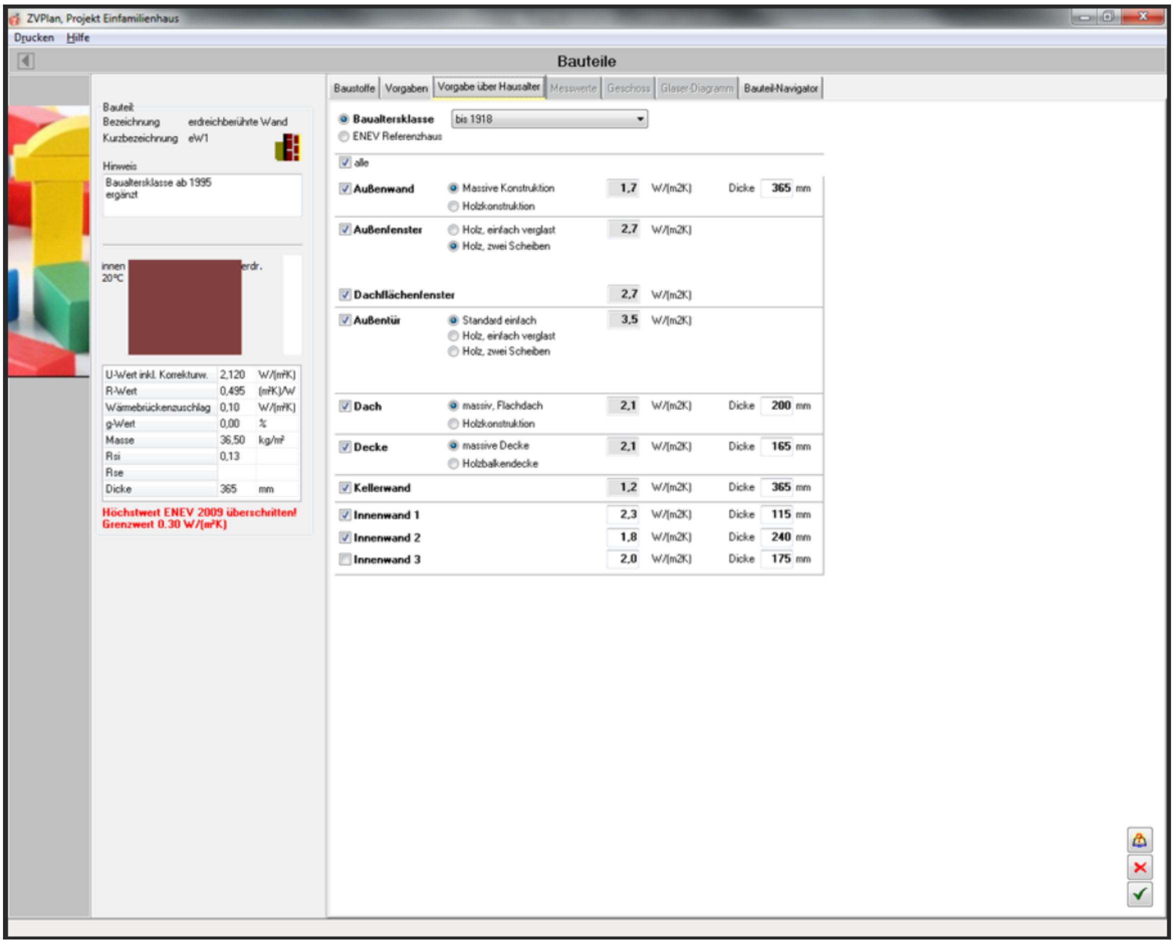


Figure 4: Here, the software tool *ZVPlan* is shown during the definition of a basement wall. While the interface appears well organized and concise, an inexperienced user is likely to have difficulties entering the required information, because technical terms are used without any explanation.
(source: https://www.zvplan.de/Programm/UWerte.aspx)

for compatibility of the building with a heat pump. After this free initial computation, users can buy the full report, a suggestion for the renovation plan and a simulation of different renovations to see the amount of potential savings. The full report contains more detailed results of the previous computation, such as the heat demand for each room and specific information on which radiators require replacement. Users can edit any entered data and recalculate the report at any time. It can also be shared with technicians to discuss the renovation. However, in order to receive a recommendation on how to renovate, the respective document must be bought additionally. This one includes a list of all necessary actions with their costs, such that the renovation can be directly commissioned to craftsmen. Note that this plan is solely a suggestion for the installation of a heat pump in the building as it currently is and does not provide any information about other possible renovations or which effects they would have. Therefor, the user can buy additional simulations. The resulting document gives an

overview of the change in heat loss as well as savings in energy, heating costs and CO_2 emissions that would result from outside wall insulation, roof insulation or window replacement. These simulations are done separately from each other and only with predefined parameters such as 16 cm insulation thickness [7], which means that the user can not deduce any encompassing recommendation for renovation. Besides, the simulation results are not incorporated in the evaluation for a heat pump or the renovation suggestion, such that those might not be adequate anymore when the simulated renovations are conducted.
The company *SkenData* [8] was founded in 2014 in Rostock and offers different services for the evaluation of buildings in terms of building value and energy efficiency. Their main product is *Wert14* [9], an application runnable on any device, which utilizes official 3D data and aerial photos in combination with complex algorithms and artificial intelligence to compute the current restoration value of buildings. Users are not required to enter a lot of data except the address and construction year of the building to be evaluated as well as whether it is under monument protection. Optionally, a percentage for value adjustment and additional equipment such as a photovoltaic system can be indicated. After registering with their name and IHK agent number, HRB commercial register number or tax number, users can buy one of three options ranging from a single building evaluation to a subscription with twenty evaluations per month. The tool can be combined with the *SkenData REST-API*, which enables companies to integrate its functionality into their own user interface or website. Besides, the *Wert14 FotoApp* promises to evaluate a building within seconds based on a single photo of the property. *SkenData* is recognized in the insurance industry and has won several awards for their services. They cooperate with leading insurance companies, which agreed to a waiver of under-insurance.
With *SkenData Portfolio Energy* the company also offers the computation of a building portfolio according to insurance number, CO_2 equivalents and energy efficiency classes. The tool is optimized to evaluate large building stocks in minimal time and targets insurance companies, realtors, banks and asset managers. Upon requesting an offer, users need to indicate their profession and select the rough number of buildings they wish to evaluate; with the options ranging from "< 100" to "> 10000". It becomes clear, that this tool is not suitable for the average owner of a residential building. The same holds for the *SkenData EnergyCheck*, which is a simplified tool, where only little input data is required. Figure 5 shows that the input mask is very compact and only asks for basic information like the construction year, the development stage of basement and attic and whether the building was renovated before. Questions like this can be answered without any expertise in building construction, but the tool only provides a preliminary energy certificate and an initial indication of the energy efficiency class. For the official certificate or the exact and individual efficiency class, an extended tool and additional data are necessary.

[7] https://www.heiz.report/de
[8] https://www.skendata.de/
[9] https://www.wert14.de/

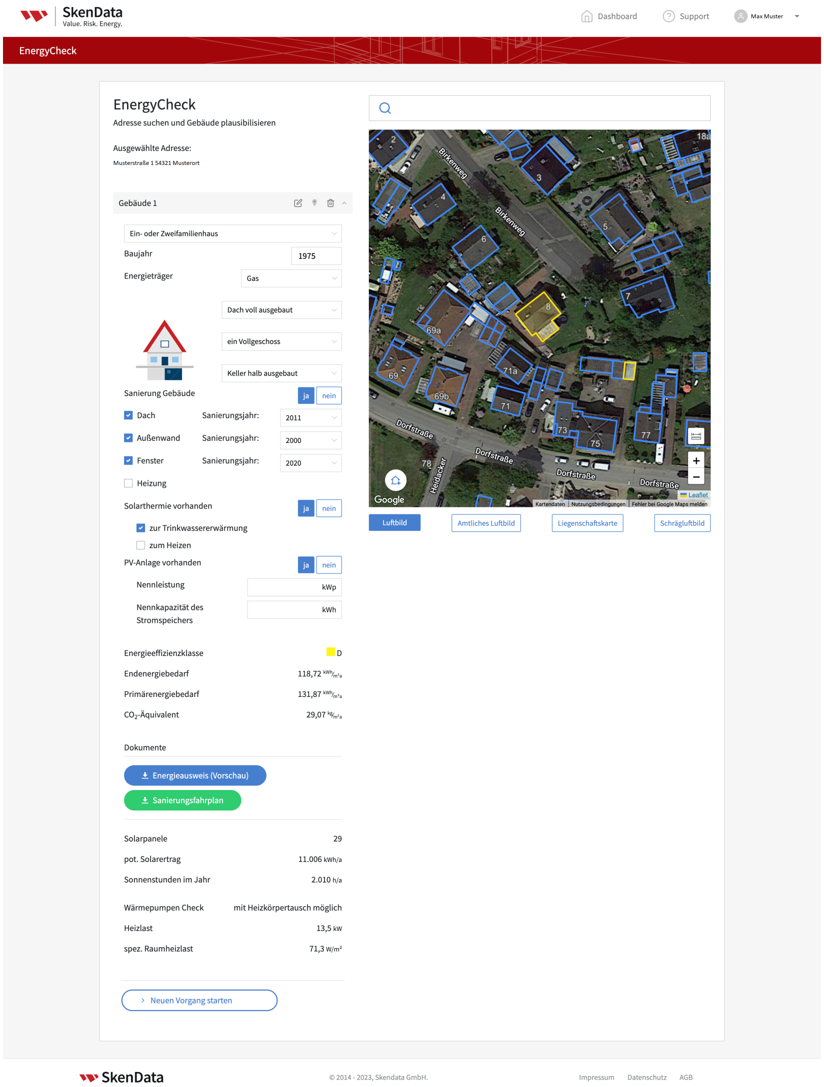


Figure 5: The input interface of the *SkenData EnergyCheck* is simple. On a map on the right, users can select the outline of the building in question and they only need to enter little information in the form on the left. These are mainly simple numbers that owners of a building should know or be able to look up in their documents without problems. The tool provides a preliminary energy certificate and an indication of the energy efficiency class. (source: https://mrqz.to/61af5d5bc1a7d600275 33d0f)

The examples show that several software companies have implemented tools for construction planners and energy consultants to assist them during data acquisition and counsel of their clients. These tools follow official standards, provide certificates and can be used to assess the current situation of buildings as well as possibilities to renovate them. However, they usually require complex input of technical data, which an average citizen is likely to be unfamiliar with. While the interface may appear concise and very helpful for experts, laypersons will probably have trouble understanding the input fields, let alone know the value to enter. Although the tools partially provide automatic completion or other supporting features, inexperienced users might feel intimidated or irritated by the mass of unknown terms and data. Such feelings are demotivating and make it hard to finish the process, even if it is possible to compute reasonable results without knowing all the technical details. Many house owners might feel like the effort is not worth it, especially when they are unaware of the potential benefits of an energetic renovation.

1.2. Contribution

In this thesis, a simple software tool for the planning of the energetic renovation of residential buildings is elaborated. It is specifically targeted to house owners without any expertise in building construction, renovation, energy efficiency or data acquisition. Users should be able to use and understand all elements of the tool without a previous introduction or intermediate explanation besides the tool's integrated support features. To achieve this, a mobile application was designed with a special focus on a user-friendly interface. In addition to an overall visually appealing look, a simplistic and intuitive usage flow was created. Based on this design, the application was implemented by research assistants of the chair with support from participants of a practical course. The application utilizes six simulations, which compute different aspects in relation to the energetic renovation of a building, namely its energy efficiency, market value, heat demand, an individual refurbishment road map, an assessment of the combustion air supply as well as costs and benefits of a photovoltaic system. In order to generate questionnaires that anyone can easily process, the required input for these simulations was converted to less technical questions. A minimalized subset of these is asked immediately upon start-up of the app, such that the building's energy efficiency, market value and energy costs can be estimated early on. In a second step, users can answer the rest of the questions in order to get more precise and encompassing results. The questions are classified into packages, allowing the successive completion of smaller questionnaires, such that users are less likely to feel overwhelmed by the large amount of required input. The computation results are presented in a simplified and concise way, so they can likewise be understood without any expertise.
The application should enable homeowners to independently enter building data and assess their options for renovation as well as potential benefits on their own. Ideally, the application should furthermore motivate users to finish the process and refurbish their house to a more energy efficient and thus environmentally friendly state. In the following, the conceived tool will be referred to as the SmartRenovation App. To assess its perceived usability as well as the effect on the knowledge and motivation of users, a small user study was conducted with a first demo version of the application.

1.3. Outline of this work

In the following Section 2, the simulations to be integrated into the application are explained and the required input is assessed to derive suitable questions that are easy to understand, such that users can provide the necessary data without any expertise. Section 3 first thematizes the technologies used for the implementation and lists some principles of design that have been applied during the conceptualization. Then, Section 3.3 describes the general layout of the application and how the functionalities are integrated. After that, the design of individual screens is elaborated in detail. In Section 4, first the procedure and then the results of the user study are depicted. These results are discussed in Section 4.3 and limitations of the study are pointed out in Section 4.4. Section 5 concludes the thesis in reference to the defined goals and contributions, and points out what is missing in the application and how it can be further improved.

2. Integrated Simulations

Overall, six simulations are integrated into the application designed in this thesis. A complete list of them is given in Table 1. Each of them is implemented in accordance with the respective standards defined by national authorities. Additionally, the energy costs of the building are computed with a simple formula. The computations usually require a lot of input data, which largely overlaps between the simulations. It is therefore stored in a shared database, such that any redundancy is avoided and for each simulation, the relevant subset of data can be extracted. The user is thereby unaware of the data storage as well as the various simulations, they can only see the results without distinction between simulations.

	Simulation	Description
1	Energy Efficiency	Calculates the energy efficiency class of the building according to DIN V 18599, which denotes the relation between consumed and lost energy, and generates an unofficial energy certificate.
2	Market Value	Calculates the current market value of the building in reference to its location.
3	Individual refurbishment roadmap	Generates a plan for the renovation of a building.
4	Heat Demand	Computes the current heat demand of the building according to DIN EN 12831.
5	Photovoltaic System	Assesses possibilities to install a photovoltaic system on the building.
6	Combustion Air Supply	Confirms whether the supply of outside air is sufficient for the operation of the installed heating system or an additional fireplace.

Table 1: The table lists all simulations that are integrated in the application. They were implemented by other students in the course of their thesis or a research assistance.

The required input is partially very technical and difficult to understand for users without expertise in the field. In order to enable average house owners to use the application, these parts are simplified to generate more easily answerable questions. Technical terms are avoided as much as possible and reasonable or explained in simple words if they are needed. The resulting questions are divided into topics to conceive smaller questionnaires that can be answered successively, such that users are not as easily overwhelmed by the large number of questions.
Irrespective thereof, users should get a first indication of their house's state early on, so they are encouraged to proceed with the questions. For this reason, a minimized

questionnaire is traversed right upon start-up of the app, collecting just enough input parameters to be able to estimate the building's energy efficiency, market value and energy costs (cf. Section 3.3). These introductory questions need to be very simple, so house owners can answer them from the top of their heads or make a reasonable estimation, because they might not have the time or be in the position to retrieve the information elsewhere when they first open the app. Any too detailed or technical data is not suitable for this initial, superficial questionnaire and needs to be substituted in reasonable ways. This can be done by choosing appropriate default values, defining limited ranges or assuming probable values based on other data. The estimated result computed from this limited input is presented to the user right after the questionnaire and can then be specified once they answer the more detailed questions.
In the following subsections, each of the six simulations as well as the computation of energy costs is described. The derivation of user-friendly questionnaires for data acquisition follows mostly the same procedure and will be explained in some examples.

2.1. Energy Efficiency

The energy efficiency of a building indicates the amount of energy that is needed to achieve a certain level of comfort inside, where a high efficiency entails that only little energy is required. Thereby the optimal value would be a final energy demand $Q^*_{f,a}$ of less than 15 kWh per square meter per year, constituting the passive house standard [22]. For an easy evaluation, the energy efficiency is usually classified into a class between A+ and H according to Table 2 and indicated on a scale as shown in Figure 6 [13]. The value depends on the building's insulation, heating, cooling, ventilation and more factors and must be computed in accordance with the DIN V 18599 standard. Thereby, the energy demands for the heating system, the tab water system and the ventilation system need to be computed separately and summed up to receive the

Energy efficiency class	**Annual energy demand in kWh/m^2/y**
A+	≤ 30
A	≤ 50
B	≤ 75
C	≤ 100
D	≤ 130
E	≤ 160
F	≤ 200
G	≤ 250
H	> 250

Table 2: The energy efficiency of a building is usually given as a class between A+ and H, where the ranking depends of the annual energy demand per square meter. This table shows the borders in energy demand that construct the classes.

Figure 6: This scale is commonly used to indicate a building's energy efficiency. It is partitioned into the nine efficiency classes, where the green end on the left of the scale indicates the best class with an energy demand below 30 kWh/m^2/y (cf. Table 2). Less efficient buildings are ranked into lower classes further on the right of the scale.

total final energy demand per year $Q_{f,a}$. The energy efficiency $Q^*_{f,a}$ is then received by relating this value with the usable area A_N:

$$Q^*_{f,a} = Q_{f,a}/A_N \tag{1}$$

Nick Feiereisen implemented a simulation for this in his bachelor's thesis [13]. The computation depends on more than 100 general parameters plus thirty parameters for each component of the building. This leads to an enormous effort in acquiring all data. In a first step of simplification, the input was reduced to a smaller number of 24 parameters, from which the complete input can be parsed based on reasonable assumptions and estimations. For example, ventilation is assumed to be not mechanical, so any questions in relation to a ventilation system are disregarded. As a result, the computed energy efficiency of buildings with mechanical ventilation can deviate by almost 50 %. Another reason for potentially significantly less accurate results is the building's architecture, since the simplification assumes rectangular dimensions, and basements to be either completely heated or not at all. It is therefore important to keep in mind that this simplification can only give an initial estimation and the extended input should be given for more accurate results. However, the assumptions are made based on statistics of the German building stock and thus expected to be met in many cases, leading to deviations of less than 5 % [32].
Table 3 lists the input that remains necessary for the simplified simulation and discusses how it can be queried from an average house owner using the SmartRenovation app. Since energy efficiency is one of the characteristics that should be indicated to the user immediately after the introductory questionnaire, the resulting queries need to be simple enough to be answered effortlessly upon start-up of the application.

Input	Unit	Description
Climate zone	Integer	The climate zone the building is located in is needed to deduce the standard outside temperature, which is relevant for the heat loss through windows and walls and therefore influences the amount of energy that is needed for heating. The simulation expects it to be given as a number between one and 15, but users are not expected to be aware of the distribution of climate zones. Instead, they will be asked for the address of the house, including the zip code. This can be converted to a climate zone based on the map given in DIN V 18599-10. To ensure that the correct location is selected, a map will be shown below the input field, displaying the entered address for confirmation.
Type of the house	String	Possible options for this field are "single_family_house" and "apartment_building". The user can easily select one of these from single select radio buttons. The information is needed for the estimation of multiple parameters in the complex input, e.g., the number of internal heat pumps [13].
Construction Year	Annual number	The construction year provides insight into the quality and insulation standards in practice during the planning of the building. It should be known by the user and can be selected from a drop-down menu, since the available options are evident.
Number of Levels	Integer	The number of levels affects the energy demand for heating as well as ventilation and is expected to be given as a plain integer. Basement and attic are not included in this number, but their existence or absence must also be indicated. Therefor, these input parameters are acquired in a combined way, where the user selects check boxes of those levels present in their house. For upper floors, users can directly enter the number or make use of plus and minus signs to add or remove floors. The resulting number of levels can be extracted from this selection.
Average height of the stories	Meter	Although stories of a house can vary in height, the simulation only takes an average value as input. Since no reasonable set of options can be given, users must enter this value as a number in a text field.

Table 3 - *Continued on next page*

Input	Unit	Description
Additional heated attic	Boolean	This parameter indicates whether there is a heated attic in addition to the number of levels given before. Since the query for the number of floors was designed in a way to answer the presence of an attic too, only the heating remains to be queried. That is, this question should only be displayed, if the box for the attic was checked. It is then simply answered by a toggle indicating "Yes" or "No".
Cellar	Boolean	Similar to the attic, the presence of the cellar was already indicated in combination with the number of levels. This input parameter can be deduced accordingly.
Heated cellar	Boolean	If and only if there is a cellar, this parameter is required to indicate whether the cellar is heated. Analogous to the heating of the attic, this is queried with a toggle if needed. Given both attic and cellar are present, the two toggles can also substituted by two checkboxes, where the user selects which of them is heated.
Width and length	Meter	To compute the overall size of the building, its width and length are needed. Note that a simple rectangular form is assumed, which is a simplification that most residential buildings in Germany conform to. The mapping between the terms of width and length and the faces of the building is irrelevant and not specified by the app. Both dimensions are queried simultaneously, such that users can assign them freely and without confusion. Therefor, two short text fields are used.
Sun protection	Boolean	This parameter indicates whether a majority of windows of the building has any kind of sun protection, e.g., blinds. The user can simply indicate this via a "Yes" or "No" toggle.
Roof orientation to the south	Boolean	The orientation of the roof is needed as input because it influences the amount of sunlight hitting the building and thus heating it up. It could be also queried by a toggle, where the user must estimate whether the degree of rotation from the south is sufficiently small. However, the integration of the simulation for a photovoltaic system allows to omit this question, since the roof orientation is automatically recognized from the address (cf. Section 2.5).

Table 3 - *Continued on next page*

Input	Unit	Description
Wall material	String	The material of the wall determines the heat transfer to the outside and thereby the amount of heat loss. It is selected by the user from single select radio buttons with the options ”Brick”, ”Sandstone”, Concrete block” and ”Pumice”. An additional button enables the user to indicate they do not know this. To simplify the selection, the options will be visualized with corresponding pictures. In the introductory questionnaire, this question is skipped, since the material can be derived from the construction year.
Wall thickness	Centimeter	In combination with the material, this affects the heat transfer through the wall. It should be entered via a short text field, but the question is skipped in case the material was indicated to be unknown, since nothing can be deduced from it then. Correspondingly, it is not asked in the introductory questionnaire.
Glass type of the windows	String	In order to minimize the questions in the introductory questionnaire, windows are assumed to have double glass for the first indication. In the detailed questions, users need to select either single glass, double glass or heating protection glass from single select radio buttons. Note that this information should be given for all windows individually to compute precise results, but for simplification, the same glass can be assumed to be on all windows.
Border type of the windows	String	Similar to the glass type, a default value is assumed here, which is aluminum. For a precise computation, users can indicate either wood, aluminum or plastic by radio buttons for each window individually or simply for all of them simultaneously.
Renovation year for windows	Annual number	Since previously conducted renovations in general are relevant for the market value, users are asked to indicate all of them with their type, building area and year (cf. Section 2.2). For energy efficiency, the window renovations are extracted from this complete list.
Solar system	Boolean	Users should indicate whether they have a photovoltaic system installed, which can be done with a simple toggle or combined with other Boolean values in multi-select checkboxes.
Construction year of solar system	Annual number	If the presence of a solar system was indicated in the previous question, the user is asked for its construction year with a drop-down menu, in order to estimate the solar system’s efficiency in energy production.

Table 3 - *Continued on next page*

Input	Unit	Description
Heating system	String	The heating system is relevant for the efficiency and emissions of the heating and is queried with radio buttons allowing oil, gas, district heating or a heat pump.
Installation year of heating system	Annual number	This can also be queried by a drop down-menu but is initially assumed to be equal to the building's construction year, so the question can be skipped in the introductory questionnaire.
Type of transfer	String	The type of transfer for heating can either be wall radiators or floor heating. For the initial estimation, wall radiators are assumed as a default value, but later users can select this from radio buttons. For additional precision, the type can be selected for each room individually.
Isolation	Boolean	This parameter indicates whether the majority of pipes is isolated and is queried by a toggle in the detail questions. For the initial indication, an isolation is assumed.
Heating storage	Boolean	A heating storage can improve the efficiency and reduce costs of heating. Its existence is also queried by a toggle but defaults to no for the initial estimation.

Table 3: These parameters are taken as input by the parser that creates an extended input file for the simulation of energy efficiency. The table describes for each of them how they will be acquired from the user or otherwise deduced.

2.2. Market Value

For the market value computation, the implementation follows the intrinsic value procedure, where the preliminary market value is defined as the sum of the building's value and the value of the property. The result must be normalized by officially predefined factors to receive the actual market value [10]. While the value of the property is simply dependent on the location and its size, the calculation of the building's value is more complex. It is based on quality values for nine weighted areas: Outside walls (weighted to 23%), roof (15%), windows and doors (11%), inside walls and doors (11%), ceiling construction and stairs (11%), floor (5%), sanitary facility (9%), heating (9%), and other technical equipment (6%) [11]. The weight corresponds to the share of the respective area on the overall building and is used to take account for its impact on the buildings value. Each of the areas must be rated with quality levels from one to five, where each level is assigned multiple properties. For example, outside walls are rated with level one if they consist of a simple timber framework, or level five if the facade is artfully designed and made of natural stone. If in an area conditions of multiple levels are fulfilled, it can also be rated partially in both levels, i.e., for example, 50% level three and 50% level four. Depending on the level, one or more ballpark prices are

[10] § 189 BewG S 3225 section 3
[11] § 190 BewG R B 190.3

selected and weighted according to the weight of the area. These prices are summed up to receive the square meter price of the whole building, which is then multiplied by the historical construction price factor. The latter is computed by dividing the construction price index of the building's construction year by the index of the year in which the ballpark prices were defined. By multiplication with the size of the living area, the construction costs of the building are received. In order to calculate the actual market value, these costs are adapted based on the value reduction due to age as well as the location and current situation of the market [5].

Since the result of this simulation is intended to be indicated directly upon the start-up of the application or adding a new house, all necessary input data should be acquired in the introductory questionnaire. The majority of it should be known to the owner of the house and can be easily requested as it is (cf. Table 6). Only the quality levels to rate the nine different areas of the house, such as roof or windows and doors, are more difficult. For each area, the quality depends on multiple characteristics, which would result in a large number of questions to be asked. Furthermore, some of these questions would be rather specialized, so a house owner might not be able to answer them straight away. For example, users may be unsure whether the non-bearing interior walls of their house can be considered as solid constructions or whether they have an above-average roof insulation. An overview of all quality levels and their characteristics per area is given in Table 7.

To avoid such difficult input data, the values need to be substituted for the initial computation. A sensitivity analysis was performed to see whether standardized values generate sufficiently accurate results: Table 4 lists the effects of changing the quality level of one single area on the overall market value of an exemplary house if all other areas are set to quality level three. They are given in dependency to the weight with which the area is considered for the quality level of the whole building. As such, the table depicts the maximal difference that can result from the quality value of a single area. Naturally, the corresponding difference in monetary value depends on the overall market value of the property, but the percentage is the same for any building, irrespective of other factors. The greatest impact of almost 15 % difference on the overall market value can be reached by areas with a weight of 23 %, which is only given to the outside walls. The roof has the second highest weight with 15 % and can cause a difference of 10,12 % of the building's value. All other areas have an impact of less than 8 %. Although these percentages can, depending on the overall market value, result in several 10.000 € of price difference, the relative difference is low, such that especially the less weighted areas can be abstracted from in the initial value estimation. Nevertheless, the estimation should be as precise as possible. Instead of setting the quality levels to a fixed value, they are therefore, whenever possible, estimated based on the year of construction of the building and any renovations conducted in the respective area. This is information any house owner is likely to know, such that it can be requested upon start-up of the application. Because not all quality levels of all areas are given with a time period and the construction standards in Germany can also not be clearly assigned to the quality levels defined for the intrinsic value procedure, not all areas can be rated based on a year. This concerns mainly the areas with less

Corresponding areas	Weight	Lowest and highest market value	Highest possible price difference	Possible procentual difference
Floors	5%	91.111,93 €		
		94.456,07 €	3.344,14 €	3,54%
Other technical equipment	6%	90.910,02 €		
		94.922,98 €	4.012,96 €	4,23%
Sanitary facilities	9%	90.304,29 €		
		96.323,73 €	6.019,44 €	6,25%
Heating	9%	90.304,29 €		
		96.323,73 €	6.019,44 €	6,25%
Windows and outside doors	11%	89.900,47 €		
		97.257,57 €	7.357,10 €	7,56%
Inside walls	11%	89.900,47 €		
		97.257,57 €	7.357,10 €	7,56%
Ceiling	11%	89.900,47 €		
		97.257,57 €	7.357,10 €	7,56%
Roof	15%	89.092,83 €		
		99.125,24 €	10.032,41 €	10,12%
Outside walls	23%	87.477,55 €		
		102.860,57 €	15.383,03 €	14,96%

Table 4: This table shows how much the quality level of a single area of the house (e.g., outside walls, roof, or floors) can change its overall market value. The weighting in the computation, mirroring the portion of the building an area constitutes, leads to a certain impact the respective area's rating can have on the overall market value. For each area and its respective weight, the table shows the lowest and greatest market value achievable from changing this area's rating, while all other areas are rated with the medium quality level three. For example, the first row of the table indicates the price difference that can result from the quality of the floors, which are weighted with 5 %. Assuming that all other areas are rated with quality level three, the example building can be worth between 91.111,93 €and 94.456,07 €, depending on the quality of the floors. This results in a range of 3.344,14 €, which is 3,54 % of the overall value, as indicated in the right two columns of the table. The percentual deviation of the market value resulting from the quality level of one area is the same for any building, independent of other factors such as size, location or construction year. Naturally, the corresponding price difference in euro is higher for bigger or younger buildings.

impact on the overall market value such as floors and stairs, so they can be set to a default value for the initial estimation. Table 5 explains the deduction of a default value for each of the nine areas. For a detailed description of all quality levels per area refer to Table 7.

Area	Deduction of quality level
Outside Walls	For the outside walls, the quality level can be easily determined based on the construction year or potential renovations, since all but the highest level are denoted with an annual number in their description. The walls are classified as level one if they were built before 1980 and not insulated since then, otherwise at least level two. Starting with a construction or renovation year of 1995, they are rated as level three and after 2005 level four. Level five is not denoted with a construction year but described as an insulation in passive house standard, which is still not common today, so it is disregarded for the initial estimation.
Roof	Regarding the roof, levels two to four are marked with the same years as the outside walls, so the borders between these levels are adopted. Again, level five is disregarded due to the high quality requirements and level one describes a roof out of roofing felt or corrugated sheets, which can also be assumed to not occur.
Windows and outside doors	This area correlates with the previous ones regarding levels two and three but is otherwise more difficult to classify. The *Wärmeschutzverordnung* effective as of January 1984 demands at least double or insulated glazing for windows to the outside in newly constructed buildings [12], so this annual year can be assumed as the border to level two. Level four is described with triple glazing, which is not regulated to this day. Its distribution in Germany is unclear and requires further research. For the estimation in this application, double glazing is assumed.
Inside walls and doors	The level descriptions for this area do not contain any annual years and seem to be rather dependent on the personal choices and available budget for the construction. Since these parameters are difficult to estimate even for the owner of the house, because they might not know the average values of the time, the intermediate level three is set as a default value.
Ceiling constructions and stairs	Analogous to the inside walls and doors, this area will probably differ independent of construction years and is set to level three by default.
Floors	Regarding the floors, quality level one denotes the absence of covering, which can be presumed to be unlikely. Otherwise, the area is also difficult to estimate and defaults to level three.

Table 5 - *Continued on next page*

[12] § 2 section 1 clause 1-2 WärmeschutzV

Area	Deduction of quality level
Sanitary facilities	Here the quality mainly depends on the number, size and equipment of bathrooms, which may be foreseeable based on the size of the living area. However, no data was found indicating how these parameters correlate. Therefore, level three is set as a default value here too.
Heating system	Since the type of heating system installed in the building is of relevance for the computation of energy costs, it is queried in the initial questionnaire (cf. Section 2.7). Users select whether they use gas, oil, a heat pump or electrical heating. While the quality level can not always be clearly deduced from this, a heat pump indicates level five. In any other case level three is set as default again.
Other technical equipment	For this area, level three denotes the presence of a meter cabinet, which can be assumed to be installed in all buildings constructed since 1985. For earlier construction years, level two is set as the default value.

Table 5: Since rating each area individually or answering specific questions about building details would be too much effort for the introductory questionnaire, the quality levels must initially be estimated. This table describes how suitable ratings are deduced from the construction year of the house and potential renovations.

With these estimations, the deviation of the resulting value from the actual market value should be sufficiently small for the initial indication. In the detailed questionnaire for the market value construction, the user should be asked specifically about each of the nine areas, such that a more precise value can be calculated. The most precise way to do this would be to ask for the particular properties of each area, i.e., for example, the material of the ceilings, their workmanship and potential decorations. From this information, the exact quality level of each area can be determined, including mixed levels. However, this procedure requires a large amount of questions when conducted for all nine areas. As an alternative, the user can be presented with a slider labeled with the official quality descriptions for each area (cf. Table 7). This should enable the user to make an informed decision and also result in a sufficiently precise result.

2.3. Individual Refurbishment Roadmap

An individual refurbishment roadmap is an official document describing suitable renovation measures for a building. It can be used to request government funding for these projects, which mainly aim to improve the energy efficiency of the house in order to reduce its environmental impact [13]. Since the application in production is not an

[13] https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestehende-Immobilie/Energieeffizient-sanieren/Individueller-Sanierungsfahrplan/

official tool, it can not issue such a certificate, but the same information can be computed by following the corresponding standards. The result is a list of recommended construction projects, ordered by their potential benefit while taking technical interdependencies into account. An example of the latter would be the connection between a photovoltaic system and an improvement of the roof insulation: If the solar modules were placed before the insulation, they might need to be removed again in order to place the buffer material. This renovation plan should be available for download as a PDF file and can then be officiated through a certified expert to be usable for funding requests.
In the current state of the application, only a demo version of the computation of the refurbishment roadmap is integrated, since the complex computation is not ready for deployment yet. The replacement implementation utilizes only the input given for the energy efficiency simulation and yields a predefined set of four renovation measures. These include the installation of a photovoltaic system, a heat pump, heating protection glass and a new facade insulation. For each of these measures, the investment costs, the expected total financial and emission savings, the yearly cost reduction and the amortization time are computed. This is done by comparing the energy efficiency of the building in its current state with a simulated configuration where the respective measures have been conducted. The costs are thereby predefined as an interval for each project.
The results of this computation are displayed in the application on a designated screen for recommendations, which will be further described in Section 3.9. They are given as a list of projects ordered by their benefits and interdependencies. In the future, each of these projects should have a corresponding detail page, where additional parameters can be set and more information about the project is given, for example, an explanation of the necessary steps to be taken or the expected time until project completion.

2.4. Heat Demand

For the calculation of the heat demand the implementation by Marvin Krebber is used, which follows DIN EN 12831-1. In his bachelor's thesis, the author describes three different calculation procedures, where the standard procedure is the most general one, which can be applied to any building but requires a large amount of technical input. The remaining two are simplified procedures: One is very similar to the standard procedure and only simplifies the ventilation heat loss, while the other simplifies the complete calculation by disregarding indirect transmission losses and heat-up power. Both of these simplifications assume that the building in question is already built and does not include any mechanical or electrical ventilation system [25]. In the following, each procedure will be described and necessary input parameters discussed.

Simplified Procedure:
In the simplified procedure, the heat load is defined as

$$\Phi_{HL,build} = \Phi_{T,build} + \Phi_{V,build} \tag{2}$$

where $\Phi_{T,build}$ is the standard transmission heat loss and $\Phi_{V,build}$ is the standard ventilation heat loss of the building.
The transmission heat loss is the amount of heat that is lost due to transmission to the outside of the building through walls, windows and other components of the thermal envelope. It is calculated for each exterior component k and then summed up to derive the overall transmission heat loss:

$$\Phi_{T,build} = \sum_k (A_k \cdot (U_k \cdot \Delta U_{TB}) \cdot f_{x,k}) \cdot (\theta_{int,build} - \theta_c) \tag{3}$$

Thereby, A_k is the area of the component k and U_k is its heat transfer coefficient, also called U-Value. ΔU_{TB} is the thermal bridge surcharge, i.e., the additional heat transmission due to thermal bridges. A thermal bridge is a spot in the building envelope, where the heat is transferred differently than in the surrounding area, caused by construction parts of different thermal conductivity or other irregularities. In many cases, this leads to locally lower temperatures on the inside of the building [34]. The resulting surcharge on the heat loss is included in the calculation in order to compensate with greater heating. $f_{x,k}$ is the temperature adjustment factor of component k, which is used to account for the ability of heat absorption of the area adjacent to the component, as for example outside air absorbs more heat than soil. $\theta_{int,build}$ refers to the standard temperature inside the building and θ_e to the standard outside temperature respectively.
Ventilation heat loss describes the heat that is lost through the exchange of air from in- and outside of the building, e.g., due to opened doors and windows or insufficient air tightness. It is calculated as the product of the internal air volume of the building, its air exchange rate, the material constant of the air and the difference between the standard inside and outside temperature. While the material constant can be simplified to a value of 0.34 Wh/(m^3·K), the air exchange rate must be measured or approximated based on the construction year or the degree of air tightness of the building.
The simulation of heat demand requires some input that users are expected to know and thus can be queried directly, and some that is needed for other simulations too and can therefore be reused. However, there are also several technical parameters that need to be simplified or substituted (cf. Table 8). For example, lays are not expected to be familiar with thermal bridges and probably do not know the thermal bridge surcharge of their house. This parameter can neither be checked in some document nor easily measured, so it is substituted by a default value of 0.1W/(m^2·K), as suggested in Krebber's thesis [25]. Another example is the air exchange rate of the building, which determines the ventilation heat loss. In this case, users are asked for an estimation of how airtight their windows are. They can choose between "airtight windows", "medium airtightness" and "significant leaks", leading to a value of 0.25 h^{-1}, 0.5 h^{-1}

or 1 h^{-1}, respectively. Although this selection is somewhat subjective, house owners should be able to assess this reasonably well due to persistent warmth or draughts. Alternatively, the airtightness can also be estimated based on the construction year or potential window renovations. Thereby, houses built before 1977, that have not been renovated, are assumed to have significant leaks, while younger buildings are progressively more airtight. This estimation can be used as long as the user has not indicated the airtightness of the windows.
Furthermore, the heat demand simulation requires several parameters for individual rooms or components to compute the roomwise heat demand or the amount of heat that is transferred through specific components like, e.g., a door to the outside. This leads to the same question being asked multiple times, referring to different doors or different rooms. In order to facilitate the input of these individual values, the rooms and components of the house need to be referred to in an intuitive way that clearly communicates to the user, which component is meant. To do this, SmartRenovation utilizes a floor plan of the building, on which the respective component can be highlighted. The plan needs to be created by the user beforehand, by specifying each room with its usage and dimensions as well as windows and doors. The basic facts such as room volume or component area are thereby implicitly given, such that they do not need to be queried anymore. Note that the creation of a complete floor plan is a significant effort, but it severely simplifies the handling of room and component specific questions. In a future version of the app, the upload and analysis of an existing floor plan should be supported. Overall, the simplified procedure for heat demand requires seven general input parameters, three room specific ones and three component specific ones. Since the heat demand is not intended to be indicated upon start-up of the app, they do not need to be queried in the introductory questionnaire.

Standard Procedure:

The standard procedure is more accurate since it takes significantly more details into account. It defines the heat load as

$$\Phi_{HL,build} = \sum_i (\Phi_{T,i} + \Phi_{T,iae} + \Phi_{T,ig}) + \Phi_{V,build} + \sum_i (\Phi_{hu,i}) \tag{4}$$

where $\Phi_{T,ie} + \Phi_{T,iae} + \Phi_{T,ig}$ is the transmission heat loss of a room i divided into shares by the type of the adjacent area. $\Phi_{V,build}$ is the ventilation heat loss of the building and $\Phi_{hu,i}$ is the heat-up power for room i that appears under standard outdoor conditions. The transmission heat loss Φ_T of a room is calculated based on the adjacent area (ground, external air or another room), the transmission heat transfer coefficients of relevant components and the temperature difference between the heated area and the environment. The general ventilation heat loss $\Phi_{V,build}$ of the building depends on the air flows between rooms and from the outside. Its computation can be simplified by assuming the absence of air flows through fans, outside wall diffusers or permeable walls, such that significantly fewer input parameters are necessary. The additional heat-up power $\Phi_{hu,i}$ needed to warm an intermittently heated room after a cool down period is optional and calculated in dependence of the floor area of the room.

Overall, the standard procedure requires at least 27 additional parameters in comparison to the simplified procedure, many of which are very technical and unlikely to be known or even understandable by lays. Explaining and elaborating a simplification for all of them would exceed the scope of this thesis. They largely overlap with the extended input for energy efficiency. For more information refer to the report concerned with the simulation of heat demand specifically [25].

Hydraulic Balancing

As an extension to the heat demand simulation, a computation of the hydraulic balancing will be integrated into the application. Therein, an optimal configuration for the heating system is determined, such that a suitable amount of heating water is led to each room. Without this optimization, the water is often not distributed effectively, resulting in rooms close to the boiler being warmer than they need to be and rooms further away not being heated properly. Regulating the water distribution often allows for a reduction in the supply temperature and thus saves energy.

The input for this computation mainly corresponds to the heat demand simulation or results thereof, such that no or just a few additional questions are necessary. However, the implementation of this computation is not completed yet, so this feature is not included in the current version of the SmartRenovation app.

2.5. Photovoltaic

With a photovoltaic system, homeowners can significantly decrease their energy costs and environmental impact, as they reduce the consumption of fossil fuels. To inform users about the benefits and anticipated costs of an installation, it is simulated with their house's specific circumstances. Based on basic information about the building and current energy consumption, the house's suitability for a photovoltaic system is assessed. To do this, public data from the Deutscher Wetterdienst and the State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV) is used to determine the solar irradiation specific for the location and gradient of the roof, so the expected yield of a photovoltaic system can be computed. The user can select the number of modules as well as the size of battery storage and receives among other data the possible degree of independence, percentage of private consumption, an estimation of the costs and amortization time. These results will be shown on the project-specific detail page for photovoltaic.

The detailed results of the photovoltaic simulation are not shown in the initial indication after the introductory questionnaire, but it should be clarified whether a photovoltaic system is eligible for the house. Since a solar system is one of the most commonly known ways to reduce the personal environmental impact, its costs and benefits are estimated early on. Thus, some of the input parameters need to be specified in the introductory questionnaire, but the more detailed questions can be deferred to the specific questionnaires later on (cf. Table 9). For example, users are asked in the introductory questionnaire whether their house is under monument protection because if it is, no photovoltaic system can be installed on the roof. This question is very simple

and house owners will most likely know the answer. Since there are only two possible options (Yes and No), the parameter can be simply queried by a toggle. While a single checkbox would also be possible, these are usually combined with a submit button [14], which is not suitable in the middle of a questionnaire.
Other parameters like the annual electricity consumption in kilowatt hours are less likely to be known. In these cases, estimations must be made or default values assumed. The electricity consumption, for example, can be estimated based on the number of residents in the building. In the introductory questionnaire, the user is therefore enabled to enter this number instead of the exact consumption, but the question should be repeated without this option in the detailed questionnaires, so the exact value is entered. Users can find it in their electricity bill, which is an acceptable effort during the detailed questionnaires, but should not be required during the introduction.
A third category of input parameters for this simulation are those that are completely disregarded in the introductory questionnaire and only queried later on. For example, the kind of roof tiles on the building determines the type of construction to mount the solar modules to the roof, but it is not as relevant to the general suitability or profitability of a photovoltaic system.
Additionally, the roof coverage and battery storage are particular parameters: Other than the rest, they do not describe the given circumstances, but specify the configuration of the system to be installed. Therefore, they are not queried in the introductory nor the detailed questionnaires but can be changed directly on the project specific detail page of the photovoltaic system.

2.6. Combustion Air Supply

The German Association of the Gas and Water Industry describes a procedure to confirm whether a building provides sufficient fluctuation of air to operate the given heating system and potentially further fireplaces [11]. More specifically, the procedure verifies that for each fireplace in the building, the volume of incoming air flows in the room is greater than or equal to the requirement of combustion air. The combustion air requirement is dependent on the total rated power of the fireplace and usually computed as 1,6 m^2 per hour for each kilowatt (kW). There are some exceptions for specific cases, where the combustion air requirement must be inferred from the manufacturer of the fireplace. If there is no such specification, the requirement is calculated with an assumed total power rate per hourly fuel throughput or per square meter firebox opening, depending on the type of fireplace.
A sufficient supply of combustion air can be provided by technical measures such as a ventilation system or by natural circumstances like openings to the outside. The given supply can be calculated from the volume of the utility room and a measured value of the air exchange rate at 50 Pascal. If the latter is not measured, a standard value can be assumed. Alternatively, the supply air flow can be estimated based on the building type, ventilation type, construction year and potential renovations since then [11].

[14]https://www.nngroup.com/articles/toggle-switch-guidelines/

The result of the computation indicates whether the given air supply is currently sufficient for the installed heating system and fireplaces. By running the simulation with the declaration of an additional fireplace the user would like to install, the suitability of the building for this additional fireplace can be checked. Neither of these functionalities is relevant for the intended initial indication of energy efficiency, market value and energy costs, so the corresponding user questions do not need to be asked in the introductory questionnaire. Nevertheless, some of them are answered therein because the data is also needed for other simulations. The remaining parameters are queried in the detailed questionnaires or can be derived from the floor plan that is created by the user (cf. Table 10).

2.7. Energy Costs

In addition to the six simulations described so far, the user's energy costs, i.e., the costs for heating, electricity and warm water are computed. Their sum is presented to the user together with the estimated energy efficiency and market value after the introductory questionnaire, so the required parameters must be given therein or estimated reasonably.

The following formula is used to compute the annual costs C_{yearly} in euro for electricity:

$$C_{\text{yearly}} = C_{\text{energy}} \cdot E_{\text{yearly}}/100 + 12 \cdot C_{\text{base}} \tag{5}$$

Thereby, C_{energy} is the working price in cents per kilowatt hour, E_{yearly} is the annual consumption in kilowatt hours and C_{base} is the base price in euro, i.e., the part of the monthly costs that is paid independent of consumption. The formula thus adds the fixed costs per year to the consumption-based costs over a year to receive the overall annual costs. As a result, users need to enter their annual electricity consumption, the working price as well as the base price of their tariff. However, it is unlikely that users know these values by heart, so they should not be required for the completion of the introductory questionnaire. Especially the base price is probably unknown, so it is estimated with a predefined default value. Users can indicate the working price via a slider, but as an alternative, they may enter the value of their monthly or yearly energy bill. The time period of the latter can be arbitrarily chosen since it can easily be translated by multiplication or division by twelve. This allows the user to enter whichever value they know best. Users are furthermore not expected to know the amount of electricity they consume in a year. While they are enabled to enter it directly, it can instead be estimated based on the number of residents (cf. Table 11). Note that such estimations are sufficient for the initial indication of energy costs, but users should indicate their actual individual values in the detailed questions later on, in order to receive more accurate results. They can look them up in their electricity bill, which is an acceptable effort for detailed questions.

The annual heating costs are computed accordingly, once users indicate the base and working price of their heating in the detailed questionnaires. However, the respective questions are not included in the introductory questionnaire in order to keep it short and simple (cf. Table 11). For the initial indication the heating costs are estimated with:

$$C_{\text{yearly}} = C_{\text{per m}^2} \cdot A_{heated} + 12 \cdot C_{\text{base}} \tag{6}$$

Here, an estimated price $C_{\text{per m}^2}$ per square meter and year is assumed in dependence of the type of heating system installed, i.e., whether the building is heated with gas, oil, district heating or a heat pump. A_{heated} is the heated area of the building in square meters, which is derived from the house's dimensions and number of heated levels. C_{base}, like before, is the base price, which is likewise set to a default value based on the heating system.
Additionally, the annual costs for warm water are estimated by the following formula:

$$C_{\text{yearly}} = 2,5 \cdot W_{\text{daily}} \cdot 365 \cdot N_{\text{residents}} \cdot T_{\text{difference}} \cdot C_{\text{energy}}/100 \tag{7}$$

Thereby, W_{daily} is the consumption of warm water per person and day in cubic meters, $N_{\text{residents}}$ is the number of residents, $T_{\text{difference}}$ is the temperature difference between cold and warm water in Kelvin and C_{energy} is the fuel price in cent per kilowatt hour [15]. The factor 2,5 results from energy losses due to the heat capacity of water, heat storage and distribution [16]. Again, users should indicate their individual values for a precise computation, but initially, all parameters are assumed to be average, except the number of residents, which is either given instead of the electricity consumption or can be estimated on its basis (cf. Table 11).
In addition to the costs, the produced CO_2 emissions can be calculated from the consumption values and will be indicated on the detail page for the energy costs. The translation of electricity into CO_2 emissions changes each year due to the development of the used electricity mix and is expected to significantly decrease in the upcoming years due to the expansion of renewable energy sources and the coal phase-out. Currently, one kilowatt hour of electricity is considered to produce about 435 g of CO_2. Concerning the heating, the translation depends on the used fuel but is given as a fixed value for each energy source. For example, natural gas produces 201 g of CO_2 per kilowatt hour and light heating oil produces 266 g [15]. The emissions of water heating are computed accordingly, in dependence of the energy source it is heated with.

[15]https://www.heizung.de/ratgeber/diverses/berechnung-der-warmwasserkosten-so-geht-s.html
[16]§ 9 HeizkostenV section 2

3. App Design

The energetic renovation of a building is a complex process where many aspects need to be considered. For example, exchanging an old heating system is an effective way to save energy in many cases, but in order to decide on an appropriate substitution, the heat demand of the building must be calculated, which depends on many factors such as the size of the building but also the amount of windows and its insulation. There are many dependencies the average house owner is likely unaware of, so it is difficult for them to plan the renovation. Although they might be willing to improve the efficiency of their home, they do not know how to approach the issue. The application designed in this thesis should therefore enable house owners to compute the measures that are suitable in their individual case by themselves. This should not require any expertise in building construction, renovations or energy efficiency. The application should be pleasant to use, such that house owners are inclined to finish the process and feel motivated to go through with the recommended measures. The most important factor to consider for this goal is simplicity: A cluttered design with a lot of information in technical language that is difficult to understand will irritate users and demotivate them. For this reason, the application was designed in a way that mostly abstracts from the underlying computations and facilitates the data acquisition for users as much as possible. Since the assessment of a building for its efficient renovation requires a great amount of detail, not all technical terms can be avoided. In some cases, users need to measure a value they might never have heard of before, in order to receive precise results. Thereby it is important that a simple explanation of the meaning of this value as well as the procedure of its measurement is provided.
In the following, all details about the application design will be discussed. Section 3.1 briefly describes the technology used for the implementation. In Section 3.2, the main principles of design, that have been applied in the conceptualization of the app, will be depicted. Then, Section 3.3 illustrates the general approach to the issue, i.e., the procedure of using the application. In accordance with this procedure, the following sections 3.4 to 3.10 will describe the design of individual screens. For a description of the remaining pages, refer to Appendix B.

3.1. Technology

A main part of the application is constituted by the input of data about the building, which might need to be acquired in different places of the house. For example, the installation year of the heating system may be read in a document, while the height of specific rooms is measured in place. To facilitate this process of acquiring information and entering it into the program, a mobile application was chosen to be implemented. For accessibility, it should run on iOS as well as Android systems. The open source framework Ionic was used to realize the program with help of the included icons and design components.

3.2. Design Principles

There are many principles of design that should be taken into account in any design process. They provide widely accepted guidelines to conceptualize user interfaces in a way that makes them easy to understand and helps users to recognize the most important components. In order to achieve a high level of usability, several of these principles were also applied during the design of the SmartRenovation app.
Since the constructed application has a complex feature set and works with a great amount of data, a key factor of the design is to keep it as simple as possible. Simplicity is essential to avoid discouraging the user but also to be able to lay focus on the important contents. In a cluttered screen, relevant information can quickly submerge, because users do not read everything. To overcome this, secondary content should be deferred to detailed screens, where only especially interested users navigate to. This leaves more space for the important contents and thus focuses the user's attention towards them [1] [17] [18]. A sufficient amount of white space between the components of a page supports this effect [19] [19].
The attention of the user can be guided through so called focal points, which create a contrast to the remaining contents and thus catch the user's eye [6]. This principle is often used to emphasize a recommended button, i.e., to implicitly suggest a desired action to the user and create a call to action [20]. By exhausting this technique with different levels of emphasis or subordination, a screen's contents can be assigned into a hierarchy, leading the user's attention from the most important component over intermediate ones to the least [21].
Irrespective of such guiding, it is important that the content is displayed in a concise way and users can clearly recognize which information belongs together or where another area begins. The so called Gestalt Laws provide several ways to group content [20]. For example, the law of proximity states that things close to each other are usually perceived to belong together. The same effect can be achieved or strengthened by applying the laws of similarity, common region or continuity. These state that objects are perceived as a group if they have a similar appearance, are enclosed in some kind of box together or placed in a continuous way [30] [20].
Additionally, the visual appeal of the application should be taken into account [28]. Therefor, balance and alignment are objectives to keep in mind for each screen. The former refers to an even distribution of visual weight, i.e., size, color and density of objects on opposite sides of the screen should be similar to create a balanced and thus more pleasant appearance. Disregarding this principle creates tension, which may be used to guide the user's attention if it is employed with caution [22]. Alignment leads to a more appealing look too, as it provides structure and unity. Especially concerning

[17] https://www.nngroup.com/articles/aesthetic-minimalist-design/
[18] https://www.nngroup.com/articles/defer-secondary-content-for-mobile/
[19] https://uxengineer.com/principles-of-design/white-space/
[20] https://www.usertesting.com/resources/topics/gestalt-principles
[21] https://uxengineer.com/principles-of-design/emphasis/
[22] https://uxengineer.com/principles-of-design/balance/

multiline text it is important for readability, as it allows the eye to jump back to a predictable point where the next line begins [23].
Moreover, the interaction should always be understandable and predictable to create a pleasant user experience. On the one hand, this means that users should be able to recognize what to do in order to achieve a certain goal, and on the other hand, it means that users should recognize functionalities on the interface and be able to predict the effect of buttons and other components [31]. The former is mainly achieved by making relevant interaction items visible instead of hiding them in a menu [24]. For the latter, the design should conform to known standards such as using widely spread icons for common functionalities like the home button, a main menu or backwards navigation. Additionally, similar looking components should maintain the same behavior throughout the application, so users can learn what to expect [27] [25].
The input of user data constitutes a large part of the SmartRenovation application, so several guidelines for the selection of input forms were consulted. They recommend suitable input fields in dependence of the type of input that is needed. For example, a free text field is clearly the appropriate choice when any text is permitted as input. If there is only a predefined set of options, the selection can be realized in several different ways. An important distinction to make here is whether multiple options may be selected at once, which means that checkboxes should be used. Otherwise, the standard recommends radio buttons, which are widely known to allow only one option. Another possibility is a drop-down menu, but this requires higher interaction costs, as it must be expanded before an option can be selected. Whenever possible, the user should be presented with all available options at once, so they can quickly read and compare them without the need to memorize any. Seeing all options allows the user to recognize the right one for them instead of needing to recall it, which is associated with increased usability [26]. If there are exactly two options, for example On and Off or Yes and No, a single checkbox can be used, but a toggle is recommended if the activation should take effect immediately [27] [28].

3.3. App Flow

For the intuitive usage of an application, it is important that the overall process is easy to understand. Generally, there are three functionalities the application should provide:
First of all, the app should facilitate the acquisition of data necessary for the integrated simulations. This is done by leading the user through a list of questions that are easy for them to understand and can be answered independently. Whenever a question contains a term or concept that users might not be familiar with, this should

[23] https://uxengineer.com/principles-of-design/alignment/
[24] https://www.nngroup.com/articles/find-navigation-desktop-not-hamburger/
[25] https://www.nngroup.com/articles/consistency-and-standards/
[26] https://www.nngroup.com/articles/recognition-and-recall/
[27] https://www.nngroup.com/articles/checkboxes-vs-radio-buttons/
[28] https://www.nngroup.com/articles/toggle-switch-guidelines/

be explained in simple language. There should also be information on why this data is needed, such that users can comprehend the necessity and are motivated to proceed with the questionnaire. However, displaying all of this information can distract users from the main content of the screen [29]. In order to guide their focus on the question itself and the respective input, such secondary information is deferred to designated overlays that can be opened via info icons.

Secondly, the application should compute meaningful results from the given input and present it to the user in a concise way. Users should be informed about the current state of their house in terms of its value and efficiency as well as about suitable measures to improve both, such that they are empowered to organize the renovation accordingly. Beyond that, they should be motivated to do so by being presented with the potential benefits and setting the necessary investments in a long-term perspective.

The third functionality is the direct activation of the user to set recommended measures of renovation in motion. This step is somewhat optional since users should be capable of doing this on their own after they have been appropriately informed about their options and benefits due to the second functionality of the app. However, the transition from informing to taking action is often cumbersome and ultimately, the goal of the application is to encourage as many people as possible to reduce the energy consumption as well as the emissions of their housing. Therefore, the application is extended with a procedure to immediately commence the detailed planning and organization of the recommended measures. This is done by specific screens, where the respective project is depicted and parametrized options can be adjusted. These options and all other relevant information can be summarized in a document and sent directly to an expert for the respective project. Therefor, a list of professionals in the area is given and the user can select one to contact.

Considering these three functionalities, the second one can be seen as the most important one. Informing the user about the state of their home and their options to improve it is the main purpose of the application, so the app is centered around this. Figure 7 visualizes the process of the application in a flow diagram. When it is started for the first time, the user is acquainted with its purpose, providing an "aha!" moment in accordance with Hulick's onboarding strategy [35]. This way the user knows what to expect and is motivated to work through the upcoming questions. Next, a login or registration screen is shown where the user needs to create an account if they have not already. Without an account, the application can not be used, since any house data must be associated with a user when it is stored on the server.

After that, the actual usage of the app begins. The user is asked to enter the most important information about their house in an introductory questionnaire, so an initial estimation of its energy efficiency, market value and energy costs can be computed. To avoid losing the user's interest or demotivating them, this questionnaire is limited to as few questions as possible, that are easy to answer. Any too detailed or technical information is estimated based on other data that users are more likely to know. After the user has completed the introductory questions, the building's market value, energy

[29]https://www.nngroup.com/articles/defer-secondary-content-for-mobile/

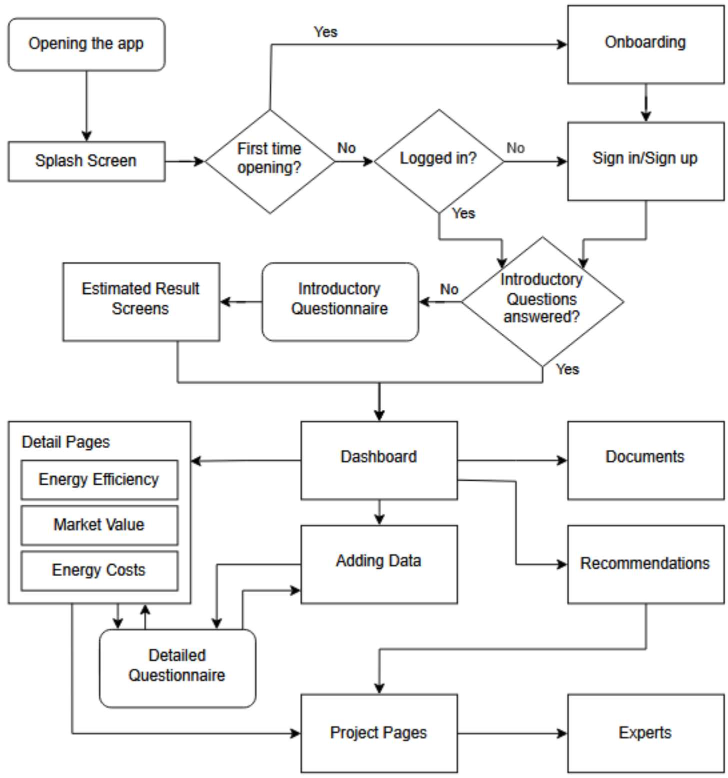


Figure 7: This diagram illustrates the procedure of the application. Upon the first opening, the user is welcomed by some onboarding screens, then needs to sign in and answer the introductory questions. Any subsequent opening leads directly to the dashboard, which provides access to all further areas of the app.

efficiency and energy costs are indicated. This way, the user gets a first impression of the situation they are in and which renovation measures might be necessary, providing a "quick win" as Hulick's onboarding strategy recommends [35]. They are then forwarded to the dashboard, where the results can be seen in concise result plots. In accordance with common practice, this dashboard enables users to see the most important information at a glance and any time the application is opened in the future, it is displayed immediately after the splash screen. It is the centerpiece of the app and provides access to all further areas including the detail pages, which show more detailed information on the computation of the building's status as well as options to improve them [1].
The detailed questions that are left out in the introduction but needed for precise results, are divided into packages, such that users can work on one package after another. This is important due to the high number of questions in total, which can easily feel overwhelming if the user were to answer them all at once. The resulting questionnaires are accessible from a designated area a button on the dashboard leads to (cf. Section 3.7). Whenever the user has given additional information, the data is included in the

simulations to refine the previous computation results and update the information on the dashboard and the detail pages accordingly.
Furthermore accessible from the dashboard is a screen listing various documents about the building that are automatically created as well as the construction page, which contains a list of renovation measures that are currently recommended for the house. They are displayed in the order their realization would be most beneficial and users can select any of them for more detailed information. From each project's detail page, the respective parameters can be set and a suitable professional can immediately be contacted to commission the project's realization. After a construction project has been initiated or finished, it is shown in a separate list on the construction page accordingly.

3.4. Onboarding

As mentioned before, four onboarding screens introduce the user to the application when it is opened for the first time. Figure 8 shows how they inform about the app's purpose and highlight its benefits to motivate the user for its usage. Thereby the first screen welcomes the user and compliments them for downloading the app, as this is the first step in reducing the emissions of their housing. The remaining three screens hint at the three main goals of the building renovation pursued by the app: Increasing the market value, reducing the regular costs of energy and minimizing the environmental impact. Each screen advertises the respective area with a graphic, a heading and a text. Thereby the heading already contains the argument, while the text gives further information. This way the user can quickly get the main points and proceed with starting the process. It is important to keep the text short, because it may otherwise be perceived as a "wall of text", leading users to feel overwhelmed and making it more difficult for them to understand the content [24].
The icon in the upper right corner allows changing the language of the text. By tapping on it, an overlay is opened, where the language can be selected. The option is meant to ensure an easy understanding for any user, but usually, the correct language is adopted from the device settings. It is therefore only shown as an inconspicuous button in the corner instead of asking the user directly to choose a language. The icon with the two speech bubbles containing letters should clearly indicate its purpose, such that no further labeling is necessary. This way, the design is kept simplistic and the focus remains on the center of the screen, following the principle of White Space [19] [30].
At the bottom, the four pages are represented by four dots, where the one representing the currently displayed page is marked by color and a bigger size. Due to these dots, the user knows at any point how many pages remain and can also use them for navigation: Tapping on any dot leads directly to the respective page. Otherwise, the user can navigate by simply scrolling from side to side or using the "Next"-button in the bottom right corner. These redundant ways of navigation are intended to serve different target groups. Users of the younger generation are likely to have experience with popular applications that often utilize scrolling as a way of navigation, such that this function

[30] https://uxengineer.com/principles-of-design/white-space/

Figure 8: These screens are shown only once when the application is started for the first time. They highlight the functionalities to the user in order to introduce them to the app and motivate them for its usage.

will come naturally to them. Users of earlier years of birth, however, may prefer the use of a labeled button if they are less experienced with social media and other mobile apps. The ”Skip”-button allows to skip the remaining onboarding pages and go directly to the following login page (cf. Appendix B), which is meant for cases where the user already knows the application from a friend or a previous installation on another device. Note that the placement of the ”Next”-button on the right follows the intuitive approach that is applied in many popular applications and web pages like, e.g., Google search results. Couper et al. argue that this placement has several drawbacks, but due to its common application, people are used to it [7]. Besides, it supports the culturally rooted mental model that the content’s continuation is on the right and spatially maps the button to the next page [28].

3.5. Dashboard

The dashboard is the centerpiece of the application and gives access to all functionalities. Its main purpose is to provide an overview of the most important information and it is designed in accordance with common guidelines for dashboards [1]. Figure 9 shows it in two different states: The left one is displayed right after the introductory questionnaire, where some detailed information is still missing and the values of energy efficiency, market value and energy costs can only be given as estimates. On the right, more precise values and additional values corresponding to the planned and recommended measures are given.

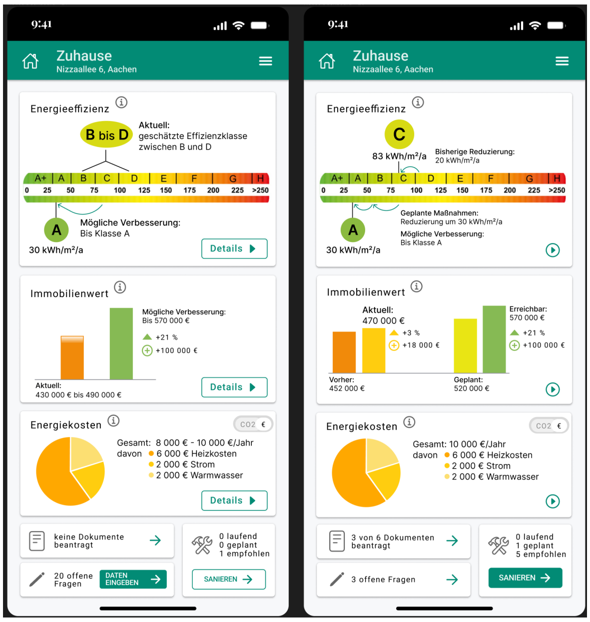


Figure 9: This is the dashboard of the application, i.e., the centerpiece from which all other areas can be accessed. It is shown here in two different states, where on the left only estimates for the building's characteristics are given and on the right, the information is more precise. The transition from the first version to the second happens automatically once the user has entered the required data for the precise computation of energy efficiency, market value and energy costs. Additionally, the tiles at the bottom allow to request various documents, add or view input data, and consult the recommendations for renovation measures.

Header and Menus

Independent of the state, a header is displayed at the top of the screen in accordance with common practice [8]. It contains a house icon, the title and address of the currently selected house and a menu icon. The house icon represents the logo of the SmartRenovation application but also resembles the usual home icon that users are probably familiar with from various other applications. Whenever some other screen is opened, tapping on this icon leads back to the dashboard [31]. However, if it is tapped while the dashboard is already displayed, it opens an overlay to select a different house or register a new one. To guide the user's attention towards this pop-up, the rest of the screen is darkened and blurred. The pop-up allows users to add multiple buildings to the application in order to refurbish them independently. For the menu icon, the hamburger known from many mobile applications is used. It opens the main menu and can be accessed from anywhere within the app (cf. Appendix B).

[31] https://www.nngroup.com/articles/consistency-and-standards/

Computation Results
There is a tile for each of the three areas energy efficiency, market value and energy costs. All of them have the same layout, although different graphics are used for visualization of the results. This adaptation is important to convey all data in the most suitable and efficient way [1]. By means of the tiles, the Gestalt principle of common region is applied to group the contents of the dashboard into topics [20] [32]. Each tile has a title in its upper left corner, indicating the topic of this tile. Next to that, a small info icon can be tapped to open an overlay that explains the respective area, i.e., its meaning and main input data of the computation. This is considered secondary information and should therefore not be initially shown [33]. Note that the area of activation for this button must be greater than just the outline of the icon to avoid difficulties in pressing it [36]. In the bottom right corner of each tile, a button labeled "Details" leads to the detail page of the respective area (cf. Section 3.6). This button is minimized to only the included arrow in the later version of the dashboard, because the additional information given in the graphics requires more space. Since this happens only after the user has answered the detailed questions, they are expected to be familiar with these buttons by then, such that their purpose is known and the label therefore not needed anymore. Note that this is based on the user's trust in the consistency of the button's functionality beyond its appearance: Since the location in the corner of the tile remains the same and the law of common region clearly indicates its belonging to the tile [32], users should understand it to be the same. Similar to the info icon, an area greater than the button itself triggers its activation.
For the visualization of energy efficiency, the official scale of efficiency classes is used, which may be familiar from house tenders. It is displayed in whole and the estimated range of the current efficiency is marked on it and pointed out by a colored sphere. The color thereby matches the one of the estimated class on the efficiency scale, such that it implicitly indicates the efficiency to the user. In case of an inefficient building, the red color of the low class can additionally signify the need for action [37]. The potentially achievable efficiency class is also highlighted with a sphere in the respective color. An arrow from the current status towards this improvement is labeled with an corresponding explanation and should implicitly define this value as the user's goal during the renovations. Once the more precise results have been computed and specific measures have been recommended, planned or even conducted, additional arrows indicate the progress made so far and expected from planned activities. This way, the user can always see where they are, what they have achieved and how much more they can improve.
For the market value, there is no official scale to be used for reference. It is instead visualized in a bar graph, where one bar represents the current market value and another one the value that can be achieved with renovations. After the user has planned and conducted renovations, intermediate values are shown accordingly. This is furthermore supported by the percentage and value in euro of the increase. The user can thus

[32]https://www.usertesting.com/resources/topics/gestalt-principles
[33]https://www.nngroup.com/articles/defer-secondary-content-for-mobile/

see the progress they have made and how much more they can achieve. Thereby the bars make it easy to compare the values, while the labels provide more exact numbers, which would be difficult to read from the bars alone. Although the latter could be facilitated by auxiliary lines, these would significantly reduce the white space and may distract from the displayed information [34]. Besides, their benefit would be small due to the large numbers.

In contrast to the other two areas, no progress is displayed for the energy costs. Instead, the costs are divided into shares according to different posts of consumption appearing in the household and as such displayed in a pie chart. This way, the user can immediately see, which post costs them the most and conclude where the highest potential for savings lies. Note that these are not necessarily the same, since users may pay a higher amount for electricity than for heating due to an electric car and multiple residents, but still have a higher chance of reducing heating costs through better insulation, for example. Nevertheless, the graphic provides an overview of the distribution of costs.

The tile for energy costs additionally contains a switch in its upper right corner, which enables the user to switch between the display of the energy costs in euro and the corresponding emissions in CO_2 equivalents. Considering the latter as costs should make the user aware of the importance of reducing them and maybe shift their focus away from the monetary aspect, as it is replaced by the emissions in the view. Although displaying both next to one another would allow a better comparison, the switch was chosen for the design, on the one hand in favor of the analogy to the shift in focus and on the other hand simply due to the limited space. A second pie chart on the dashboard would displace the remaining tiles at the bottom of the screen, such that scrolling would become necessary to see them. Due to their importance for the renovation progress, they should be visible at first glance.

Additional Navigation Tiles

The document component leads to a page where various documents can be prepared and requested. This functionality will be further explained in Section B. On the dashboard, it is only represented by a small tile labeled with a document icon and a textual indication of the amount of documents requested so far. A small arrow on the right clarifies that the tile can be tapped for more detail and is not just informative.

Below that, the number of unanswered questions is indicated with a pencil icon, hinting at the possibility of entering data here like in a paper form. As long as the computation results are only estimated due to missing data, this tile contains a filled button labeled "Enter Data" acting as a call to action. Due to this application of the focal point principle, the button should attract the user's attention, such that they continue entering data [6] [35]. Additionally, this is one of the few instances where uppercase letters are used. While they are usually avoided because they are harder to read, they are used here to further emphasize the button [29]. Since the label is short, it is still

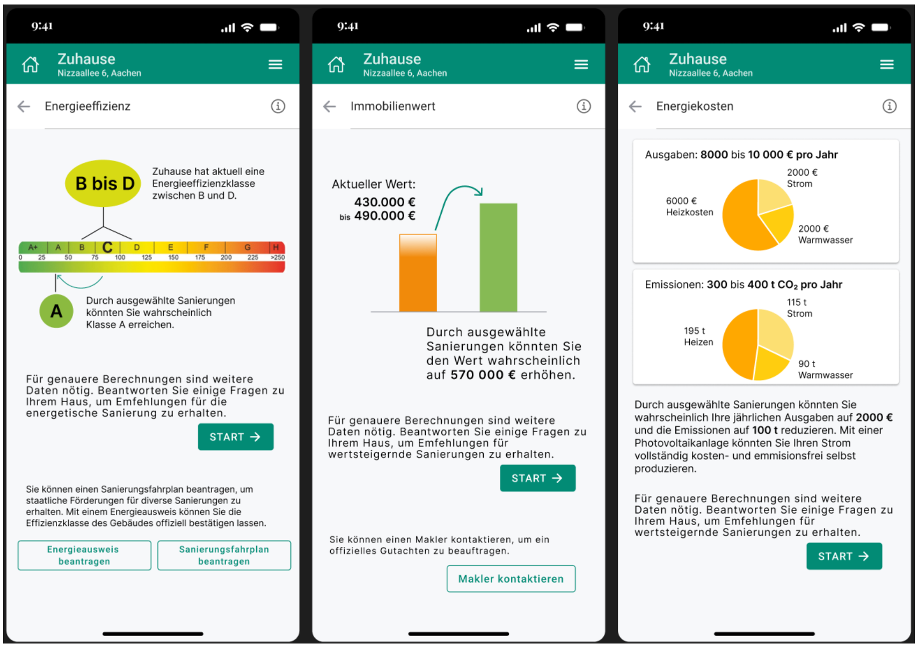
[34] https://uxengineer.com/principles-of-design/white-space/

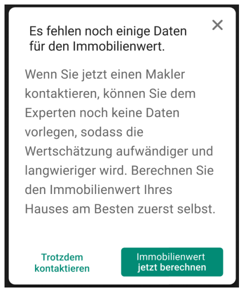
[35] https://www.usertesting.com/resources/topics/gestalt-principles

well readable. Once the questionnaires have been answered sufficiently to create precise results, the primary button is replaced by a plain arrow, such that the tile is less in focus but still recognizable as selectable.
Counterposed to that, the tile on the bottom right contains a secondary button in the beginning, which is filled to be primary once the results are computed precisely. This is because it leads to the recommended measures for renovation, which can not be conclusively given without detailed data. The tile's purpose is clarified through the button's label ”Refurbish”, which is likewise written in capital letters for emphasis. A construction icon additionally hints on the purpose of the tile and the number of running, planned and recommended projects is indicated to give an overview of the current state of renovation.

3.6. Detail Pages

The detail pages provide, as the name suggests, more detail about the main areas energy efficiency, market value and energy costs. Figure 10a shows the initial version of the three pages that are accessible over the respective ”Detail”-button on the dashboard when the results are still estimated. Each of them contains at the top the graphic summarizing the estimated results that is already known from the dashboard. This is likely what the user expects by tapping on one of the result tiles and creates consistency. In case of the energy costs, monetary expenses and emissions are both shown at once, since the space suffices here and more information is purveyed this way. A short text below the graphics on each page points out to the user that these are only estimations and that further data is needed. It is paired with a primary button labeled ”Start”, which should incite the user to begin the respective questionnaire due to the focal point principle [6]. The questionnaire contains all questions relevant to the detail page it was accessed from, in order to receive more precise results and recommendations to renovate. This is the third and last instance where uppercase letters are used to further emphasize the button. Again, the label is still well readable due to its shortness.
On the page for energy efficiency, two additional buttons allow requesting an official energy efficiency certificate or an individual refurbishment road map. The purpose of these documents is shortly explained to the user, stating that the certificate officially confirms the efficiency class and the road map can be used to request government funding for reasonable renovation measures. Similarly, a report of the market value can be requested from a realtor over the market value page. All of these buttons are secondary at this stage of the usage, i.e., they are not used as a call to action. This is because the effort for the expert can be significantly reduced if the user collects the data themselves in advance, such that the expert only needs to confirm their correctness. Finding an expert willing to issue the respective document can become easier this way. If the user selects one of these buttons before entering the relevant data, this circumstance is highlighted to the user in a pop-up warning as shown in Figure 10b on the example of requesting an efficiency certificate. While the warning is displayed, the background is darkened and blurred, so it does not distract. The headers of the





(a) The pages in the left image display a detailed view of the computation results regarding energy efficiency, market value and energy costs. They are accessed via the respective buttons on the dashboard and only show the estimated results at this stage. This is pointed out with a short text on each page, proposing to answer further questions for more precise results. A corresponding primary button leads to the questionnaire needed for the computation of the specific property. The pages for energy efficiency and market value additionally provide options to request official documents or contact experts.

(b) The warning shown in the right image appears when the user tries to request an energy efficiency certificate before they have entered the relevant data. While they can still issue the request, they are advised to work on the questionnaire first, so that the certificate creation is less effort for the expert. Similar warnings appear upon pressing the buttons for requesting a refurbishment road map or contacting a realtor. They are shown in the center of the screen while the background is darkened and blurred.

Figure 10: Figure 10a illustrates the detail pages for the computation results before the detailed questionnaires have been worked on, i.e., there is still data missing and the result values are only estimated. Users should add the data before taking further steps, which is explained to them in the warning shown in Figure 10b. It appears upon tapping on any of the buttons for requesting an official document.

page remain clearly visible because they indicate the context of this warning and the user can thus see the house and area in question. It is also still possible to access these headers to return to the dashboard. Otherwise, the pop-up can be closed by tapping on the cross at the upper right corner, like users are habituated to from most desktop applications, or by tapping anywhere outside the pop-up. However, the window also contains two buttons, one of which is designed to act as a call to action. It is positioned

at the right to symbolize the proceeding and leads to the open questions that should be answered. The other button is not framed and labeled with "Request anyway", which makes clear that this is advised against. Analogous warnings are also displayed upon tapping the buttons for requesting a refurbishment road map or contacting a realtor.
On the energy costs page, there is an additional text forecasting the possible savings in euro and CO_2 emissions. It advertises the installation of a photovoltaic system and estimates how much of the household's electricity consumption could be generated by it. In the example of Figure 10a the needed electricity could be completely self-produced, but any percentage might be given here. A photovoltaic system is a popular tool to reduce the environmental impact and energy costs of a residential building and with this information, the user already gets a feeling how they could benefit from it, although there is not enough data yet to give a specific recommendation.

Refinement of the Results
When the user does as they are incited to do and chooses to enter the information needed for precise results, the respective questionnaire is opened. This questionnaire consists for each of the three detail pages out of all questions that must still be answered for the specific computation. Note that the user might have worked on some questions already via the area designated for this purpose, which is accessible via the "Enter data"-button on the dashboard and will be further discussed in Section 3.7. Thus, the remaining questions that are asked from the detail pages can differ. The overall needed questions are deduced from the necessary input for each of the simulations as described in Section 2. The resulting questionnaires conform to the design depicted in Section 3.8. After the user has answered all questions, they are led back to the detail page they came from. It then shows more precise results computed based on the detailed input but is otherwise composed the same way as before (cf. Appendix B).

3.7. Adding data

By tapping on the tile in the bottom left corner of the dashboard, users get to the area of the application where further data can be added. Additionally, previously answered or marked questions can be revised, in case the user initially made a mistake or the circumstances changed. Figure 11 illustrates the structure of this area. It is divided into three tabs, which the questions are assigned to based on their status of processing, i.e., whether they are open, marked or answered. Tabs were chosen here as a design element because all three of them belong to the same area and simply provide different views on the context, which is the main purpose of tabs. Users are also not required to compare the contents of the tabs, such that they do not add any cognitive load or interaction cost [36].
In the beginning, all detailed questions are located in the first tab, for the open questions, since they have not been answered yet. Only the ones included in the introductory questionnaire can be found in the right tab for answered questions, where all

[36]https://www.nngroup.com/articles/tabs-used-right/

other questions will also be moved to once the user has answered them. The tab in the middle is intended for marked questions, i.e., those that the user has seen before, but where the user either did not know the answer at all or was unsure about it. In such a case, they can tap on the flag that is shown in the upper right corner of each detail question screen in order to revise it at a later time (cf. Section 3.8). The question then appears in the middle tab, but should still also be retrievable from the first or the third tab, depending on whether the user skipped the question or entered an estimated value. Users may expect a question they have answered to be found in the answered questions tab because it fits in this category too, even if the value was guessed and they marked it for future revision. Employing polyhierarchy improves findability in such cases [37].
The order of the three tabs should be intuitively understood by the user, as it follows the usual transition of the questions between them. Each question is initially to be found in the left tab, can then be moved to the middle one and finally should be answered to arrive in the right tab. However, note that not all questions will be moved to the middle tab at some point and ideally the user should be able to answer all questions directly, even if some might require them to check documents or measure some circumstances in their house.

[37] https://www.nngroup.com/articles/polyhierarchy/

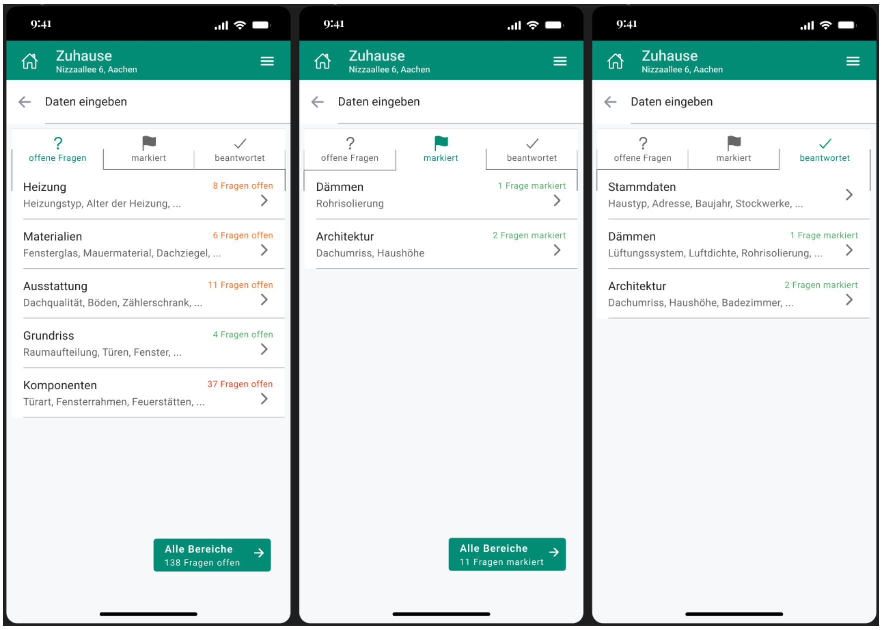


Figure 11: The area for adding data is divided into three tabs to access the unanswered, marked and answered questions separately. This way, the user can easily retrieve questions they wanted to revise and edit data according to changes in the building. In each tab, the questions are further distributed in categories for a better overview.

Categorization of Questions

For a better overview, the questions are further divided into categories in each tab instead of listing them all directly. The titles and contents of the categories were determined based on how all questions can be reasonably divided into smaller groups. Each of them should contain roughly the same amount of questions which relate to a common topic. This makes the process more manageable because users can work on the questions in topic specific packages, such that they do not get as easily overwhelmed by the great number of questions. Nevertheless, a button at the bottom of the screen allows to go through all open or marked questions, irrespective of the category. Since the user should ultimately answer all questions, this button is colored to act as a call to action. It is labeled with the total number of questions with the respective status, so the user can estimate the amount of time they will need to work on them. Note that the processing of questions can be paused at any time by simply returning from the questionnaire or closing the application. All entered data will be saved automatically and the questions will be reassigned to the tabs according to their status. The category remains thereby the same and is independent of the transition between tabs. This supports the user's orientation among the questions, such that they can retrieve specific ones more easily even after they have been moved due to their status.
In addition to the category title, the categories are labeled with the short title of the first questions contained therein as well as the number of the contained questions. The former makes the categorization more transparent to the user and thus supports their orientation. The latter enables the user to track their process and select the next category to work on based on its remaining size.

Opening of Categories

Another difference between the tabs besides the contained questions is the behavior upon tapping on the categories. In every tab, a caret on the side indicates that the categories can be tapped to see more, but only in the tab of open questions this leads directly to a new page with the questionnaire containing all questions of the category. Here, each question is displayed separately in its detailed version according to the design described in Section 3.8, occupying the whole screen, such that the whole query as well as answer options and optionally information icons for further explanation can be seen. This is important for the open questions tab because these questions have not been seen before, such that any abbreviation or simplification might be misunderstood or more difficult to answer. The user can scroll through the questionnaire and answer all questions one by one, analogous to the process of the introductory questionnaire. Again, the questionnaire can be paused at any time by selecting the arrow in the header, which leads back to the overview of categories.
In the tab for marked questions, opening a category means expanding a list of the contained questions that have been marked. The list thereby only contains a short title of each question with another caret, which allows to open the question in detail view, i.e., the way it would also appear in a questionnaire. This view also contains the chevron arrow at the bottom of the screen, indicating that the user can scroll down to the next marked question in the list. This way the user can go through the whole list

of marked questions and answer them all as they would in an ordinary questionnaire. At the same time, they are able to navigate to a specific question in the list after they have, e.g., looked up the respective information in their documents. Depending on the number of marked questions, scrolling through all detail views to find the place to enter a specific piece of information would be a significant overhead.
Note that expanding a category to see the list of marked questions therein should never trigger automatic scrolling since this often leads to disorientation. In case the list for one category exceeds the page, the accordion header should persist at the top of the screen to allow easy collapsing without the need to scroll back up [38]. However, this case should usually not occur, as users are not expected to mark this many questions. Similarly, such scrolling would not be suitable for the third tab, which contains the answered questions. Considering the use case that a specific characteristic of the building changed or the user realized an earlier mistake, they should be able to easily find and correct that error. The question has been seen and answered before, such that the query should be known to the user. Therefore, the questions here are given in a list where each item contains a short title of the question as well as the currently assigned value and a direct option to edit it. The appearance of the latter depends on the type of question, e.g., a short text input is displayed with a pencil icon which opens the device's keyboard and a drop-down menu is displayed with a caret arrow that can be used as such. In most cases, this setup should suffice to enable the user to correct any earlier mistake. However, it might happen that users are unsure about the aim of a question and want to read it again or consult the info icon for further explanation. For this scenario, the question item can be tapped and held to open a pop-up menu. This possibility is not indicated in any way to the user, because no clear yet unobtrusive way to do that was found. However, the long press is a common gesture in mobile interfaces nowadays, such that users can be expected to try it when they are looking for further options [39]. The menu allows to either open the question in its detailed view, mark it for later revision or delete the previous response to move it back into the tab for unanswered questions. Note that deleting an answer can affect the computation results and thus alter the information displayed on the dashboard or even disable the computation of specific values. To indicate this risk to the user, the corresponding option in the menu is written in red color and must be confirmed in a pop-up warning before it is performed.
Note that the difference in behavior between the tabs in spite of the same design violates the design principle of consistency, as users will expect the reoccurring list items to trigger the same effect on each of the three tabs. This might lead to confusion and reduce the usability of the application due to lower predictability [27] [40] [41]. Nevertheless, this design was chosen purposefully in order to support the specific use cases of each tab in the most comfortable way. Applying the same behavior to all of them would not meet all individual needs, regardless of which version would be chosen. Al-

[38]https://www.nngroup.com/articles/mobile-accordions/
[39]https://www.nngroup.com/articles/state-mobile-ux/
[40]https://www.nngroup.com/articles/consistency-and-standards/
[41]https://www.nngroup.com/articles/tabs-used-right/

ternatively, the appearance of the list items could be adapted for each tab, such that the difference in interaction becomes visible and thereby predictable, but this would additionally disrupt the consistency of the visual design between tabs. Users might then not recognize the categories to be the same in each tab and comprised of a static set of questions [42]. For these reasons, the drawbacks of the unexpected difference in behavior are accepted here. Note also, that these drawbacks will likely be small because the behavior is still similar: In each case, tapping on the categories will open the contained questions, they are simply displayed in a different way.

Visual Design

For the visual design of the tabs, special attention was paid to their labels and to highlighting the currently selected tab. Concerning the former, it is important to use only a few words to make them easily scannable while easy to understand [42]. These requirements are met with the labels ”open questions”, ”marked” and ”answered” accompanied by fitting icons. Although the first of these could be shortened to just ”open”, this might be irritating with the header referring to data instead of questions, since ”open data” is unclear.
The selected tab is indicated by displaying its label in the application's typical green while the others are in a light gray. Because there are three tabs, this differentiation would already suffice, but it is emphasized by gray lines leading from the tab labels downwards, such that the label of the selected tab appears to be attached to the displayed content. This is not only more visually appealing due to the clear structuring but also mimics physical index cards, which further simplifies the understanding and reduces cognitive load on the user [42].

3.8. Questionnaires

Each of the input parameters for the simulations described in Section 2 must be either directly entered by the user or deduced from some other input parameter. The resulting questions are each displayed on a separate screen and collected in questionnaires the user can scroll through. This way, users can focus on one input at a time, do not need to choose the order of processing and do not get overwhelmed by cluttered screens [1] [17] [19]. For consistency between the questions, all of them conform to the general design shown in Figure 12, whose components will be depicted in the following.
At the top of the screen, the main header displays the building's name and address. The secondary header indicates the currently opened category and contains a back arrow leading back to the overview of questions, specifically to the tab the questionnaire was opened from. Both headers provide context to the current questions, such that users know where they are and which house they are working on. The main header additionally contains the home button, allowing immediate navigation to the dashboard. Note that both headers can only be constructed after the creation of a building, which means that they are not displayed during the introductory questionnaire.

[42] https://www.nngroup.com/articles/tabs-used-right/

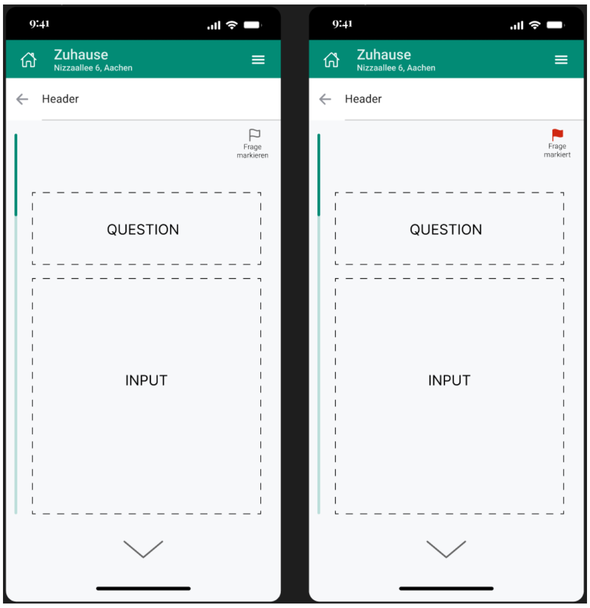


Figure 12: This image illustrates the general template of a question in the application. It consists of a header, a progress bar on the left, the question itself in the center, a marking flag on the right and the scroll indicator at the bottom. During the introductory questionnaire, there is no header and no flag to mark the question, because the building for context has not been instantiated yet and answers are mandatory. Other than that, all questions follow this design, where the query is displayed in the upper half of the screen and some kind of input field is given below.

Another difference between the introductory questions and the detailed ones is the flag in the upper right corner, which can be used to mark single questions in order to answer them at a later time. Since the introductory questions need to be answered prior to the computation of the first results, they can not be deferred like this. Upon tapping on the icon, the flag becomes red and the label changes to "marked", indicating that this question can now be found in the tab for marked questions on the screen for adding data. Note that this does not mean it disappears from the tab it was previously assigned to. Depending on whether the user has entered a value, it can still be found with the open or answered questions respectively. This principle of polyhierachy ensures that users can later retrieve the question easily, even if they do not remember they have flagged it [43].
On the left edge of each question screen, a green bar indicates the progress the user has made while scrolling through the questionnaire. The light green bar represents the complete list of questions and is successively covered by the darker color. This way the user can watch their progress and estimate how many questions are left. Note that some questions are dependent on previous questions and may not be displayed

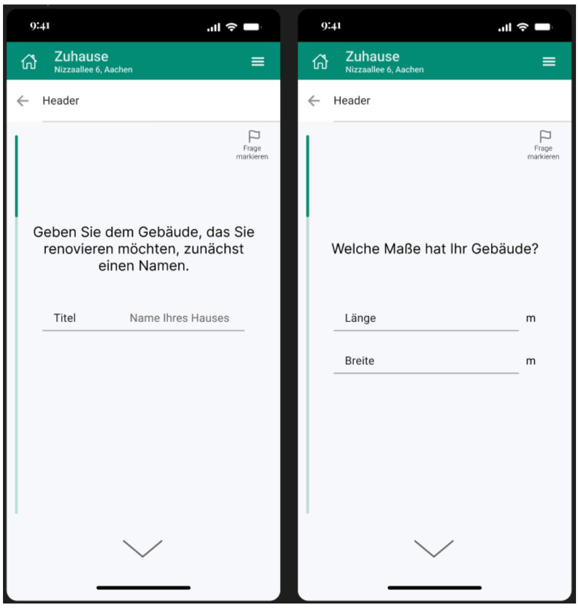
[43]https://www.nngroup.com/articles/polyhierarchy/

if the previous answer renders them unnecessary. The exact number of questions is therefore not definitively known in advance, such that the amount of change in the progress bar is not necessarily the same for each question. This is also the reason why more conclusive dots as in the onboarding pages (cf. Section 3.4) can not be used here. The bar is furthermore specifically not intended to be used for navigation among the questions, since they should be answered in order. This is visually supported by the position of the progress bar on the left side of the screen, while scroll bars are usually located on the right side [9]. Besides, the bar is filled up with a darker color as opposed to moving a small handle down.
Nevertheless, the questions are navigated by scrolling, which is indicated by the chevron arrow at the bottom of the screen. It points downwards to show the direction to proceed in. The scrolling is thereby discrete, i.e., sliding up on the screen once moves the current question all the way up, irrespective of how long the sliding movement is. The next question occupies in any case the whole screen, i.e., each question will be shown in the center of the screen. Only for the short amount of time during the transition between questions, two adjacent ones can be seen partially. The focus of the user is thus always directed towards one question at a time.
As an alternative to the scrolling, the chevron arrow can be tapped, which has the same effect. Users can also scroll upwards in case they realize some mistake, but this is usually not expected and therefore the possibility is not indicated in any way.
For each question, the query is inserted in the designated area on the upper half of the screen and depending on the data type, a suitable input method is displayed below. Note that the exact position of the question as well as the input area is adjusted in accordance with the size of the screen and the individual input field. They should be balanced to appear in the center of the screen. In the following, several examples serving different kinds of input are given.

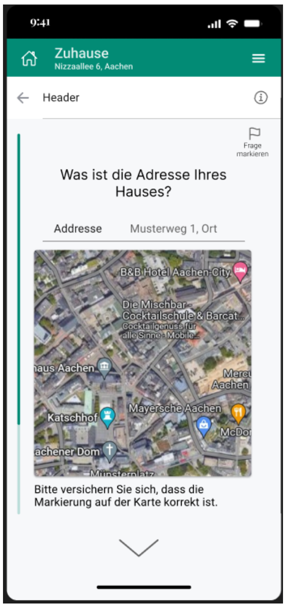
Text input

The most straightforward kind of input is a text field where the user directly enters the requested value via the keyboard. For its design, it is important to include an unambiguous label that clarifies what kind of input is expected here, such that the user knows what to do. To minimize strain on the user's short-term memory, such labels should remain visible during typing, i.e., using them as placeholders inside of the field is disadvantageous [44]. Figure 13a shows how this is realized in the SmartRenovation app for entering a title for the building to be renovated and the production of an existing solar system. Placeholders are only used to signify the exact place to type if this may otherwise be unclear. Note, that any input field in the questionnaires is preceded by a question querying the required input, which may also sufficiently act as a field label. Regardless, a text field entails high interaction costs in a mobile application, since the user first needs to open the keyboard and then type the whole input, in contrast to tapping only once to select an option out of a predefined set. To minimize the interaction, users can be supported by providing automatic completion during typing.

[44]https://www.nngroup.com/articles/form-design-placeholders/



(a) In case of an arbitrary title or only a number, automatic completion can hardly be applied effectively. However, a field where only numbers are expected can be supported by opening the number block of the keyboard directly.



(b) The address input can be effectively facilitated by offering automatic completion with suitable suggestions in the area of the used device.

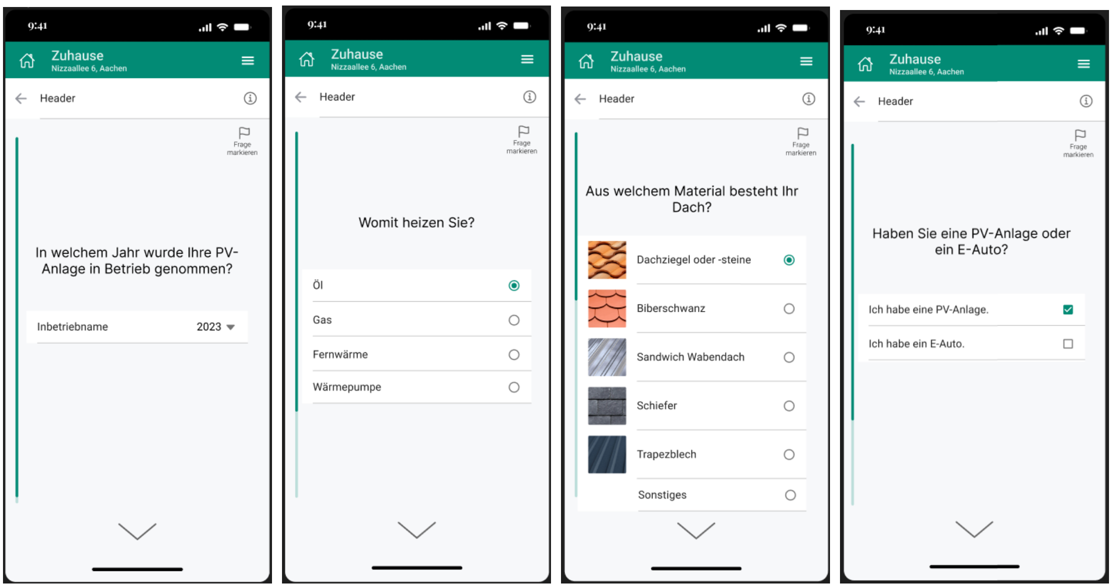
Figure 13: This figure shows different versions of text input fields. This type of input requires a high amount of interaction due to the usage of the keyboard, which should be mitigated as much as possible. Automatic completion is a common way to do this but is not always possible due to arbitrary and short inputs.

In case of the building title, this can hardly be realized more than the keyboard integrated word recognition already does, since any arbitrary title can be chosen. Neither the electricity production can be effectively suggested, but here, the input can be supported by opening the number block directly instead of the usual keyboard, since only numbers are expected. For the input of the building's address, shown in Figure 13b, automatic completion can be applied very effectively. Suitable addresses are suggested to the user while they type, enabling them to select the right one and thus speeding up the process significantly. To increase the probability of suggesting the correct address, the device location can be used to focus on the local area. Once the address has been selected, the location is shown on a map for the user to confirm it. It is thereby marked by a red pin resembling the one used on Google Maps, which the user is likely to be familiar with. In case the address could not be found, an error message is displayed.

Selection types

Whenever the possible answers to a question are predefined, the user only needs to select one or more options out of the given set. This can be done in different ways depending on the number of available options and whether they are self-explanatory or even predictable for the user. One version is the drop-down menu, which is used when the options are obvious, so the user does not need to see them all at once to compare them and choose the right one. For example, whenever a year is queried, the user will intuitively understand that all possible answers are annual numbers. They will usually know the correct one without looking at the options and thus do not need to see them laid out. Figure 14a shows the design of such a drop-down menu on the example of the selection of the installation year of an existing photovoltaic system.

There are also questions, where the available options might not be as clear in advance. For example, inexperienced users may be unaware of which kinds of heating systems exist, so when the user is asked for the type of heating system that is installed in their house, the selection can be supported by enabling them to conveniently read through all the options and subsequently select the most fitting. Figure 14b visualizes this type of question. In some cases, images can be used to clarify the available options



(a) Drop-down menu (b) Single select (c) Single select with images (d) Multi-select without images

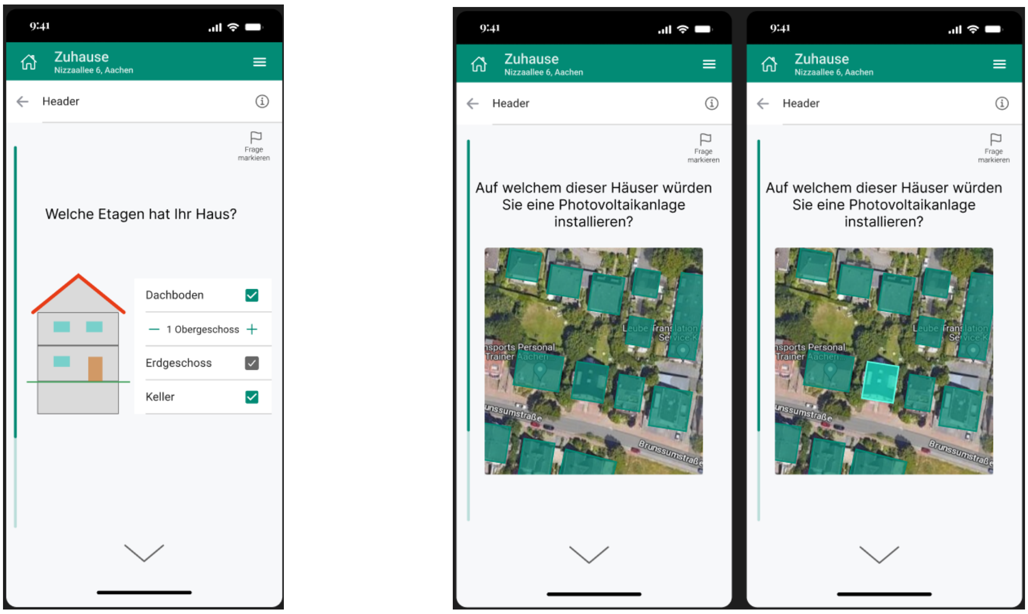
Figure 14: These are different input types where the user selects one of several predefined options. In case the options are predictable for the user, a drop-down menu suffices, but for more complex questions the possible responses should all be visible at once to provide an overview and allow comparison of the options. In some cases, icons or images can clarify the meaning of the textual labels and thus facilitate the selection. If multiple options can be selected, this is indicated by using checkboxes instead of radio buttons.

if the textual label is not sufficiently descriptive. E.g., users may not know the name of the type of roof tiles on their house but recognize them from a picture. Figure 14c illustrates the design of such a case.
Irrespective of whether images or included, some selection questions may allow multiple answers, which is indicated by using checkboxes instead of radio buttons. This is a common practice and should be a clear indication to users, especially if the context of the question also suggests the possibility of multiple correct answers [45]. An example without images is given in Figure 14d. Besides the checkboxes, the design is equivalent to the single selection, and the variant with images is treated analogously.
Furthermore, there is the toggle, where users can only choose between two mutually exclusive options. Mimicking a light switch, it is especially suitable when there are only short options like On and Off or Yes and No. Thereby, it is important to provide both state descriptors as labels on the sides in order to communicate the current selection state unambiguously. The same functionality may be provided by a single checkbox, and one or the other may be more fitting, depending on the specific use case. For similar situations, the choice for one of them should be consistent [46].
In addition to these regular selection types, there are some special cases designed for specific questions. One of them relates to the selection of levels present in the building, where a graphic of the building is interactively constructed on the side (cf. Section 2.1, 2.2). Figure 15a shows this question, where there is a checkbox for each of the levels basement, ground floor, upper floor and attic. Since every house is expected to have a ground floor, this box can not be deselected and is grayed out. Since the number of upper floors can be arbitrarily large, querying it by means of multiple checkboxes would exceed the screen size. Instead, the number can be in- or decreased by a plus or minus sign respectively, or given directly in a text field. The graphic on the left immediately indicates any changes made to the checkboxes, such that the user can quickly recognize, whether it resembles their house.
Another specialized kind of selection is the selection of a building on a map. This case is visualized in Figure 15b and does, in contrast to the previous types, not utilize any kind of list to display the selectable options. It is needed, e.g., for the initial definition of the building the user wants to renovate, such that the LIDAR and satellite data regarding this building can be extracted and applied. After the user has entered the address of the building in question, the respective area is displayed on a map, where the outlines of potential buildings to be renovated are marked. Upon tapping on one of these outlines, the color of the marking changes, differentiating it as being selected. Since neither radio buttons nor checkboxes are used here, it is hard to indicate whether this is a single or multi-select question without stating it explicitly. To mitigate this, the question should be phrased unambiguously.

[45]https://www.nngroup.com/articles/toggle-switch-guidelines/
[46]https://www.nngroup.com/articles/toggle-switch-guidelines/

Combined inputs

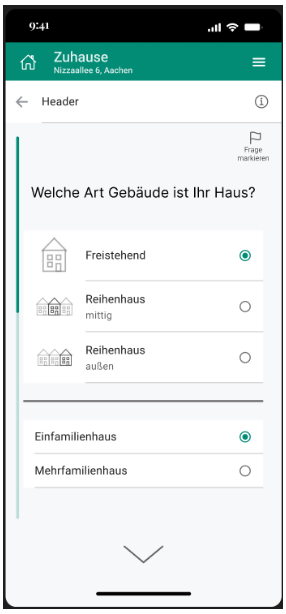
In some cases, it can be advantageous to combine multiple input fields in one question screen, because the queries are similar or closely related. A simple example of this is the combination of two questions regarding the house type, which have different sets of selectable options but the same query phrase. The integrated simulations require the user to indicate whether the building is a single or multi-family house as well as whether it is detached or a row house. Both parameters can be queried by the phrase "What kind of building is your house?", but they are independent of each other. While the question could simply be asked twice with different options to select, this might confuse the user as they feel like they are answering the same question twice, and it would render the short title of the question to be displayed in the list of questions ambiguous (cf. Section 3.7). This is solved by offering two sets of single select radio buttons under the same question as shown in Figure 16a. As a result, the user needs to select two radio buttons on one page, which might appear unintuitive, since radio buttons usually indicate a single selection. It is therefore important to visually separate the two sets very clearly, which is done here with some distance in accordance to the



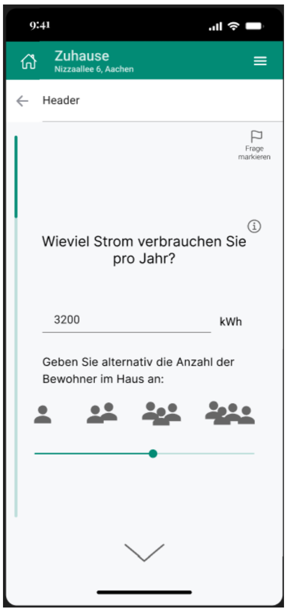
(a) The number of levels is given by selecting the floors from checkboxes and increasing the upper floors with the plus sign. For convenience in case of many levels, the number of upper floors can also be entered directly. The ground floor can not be deselected, as every building should have one.

(b) For the simulation of a photovoltaic system, the building to install it on must be selected from a map. Selectable buildings are thereby marked in green and highlighted in a brighter color when the user taps on them.

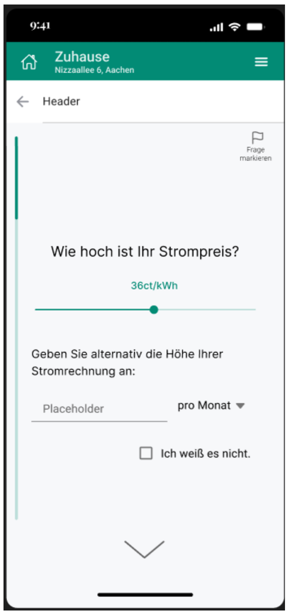
Figure 15: These figures show alternative types of selection. On the left, a graphic of the building is interactively constructed upon selection of the building floors and on the right, the correct house needs to be selected from a map.



(a) Two sets of options for the same question can be combined in one screen to avoid a duplicated question. It is important in such a case to separate the two input sets clearly, so the user can see that multiple options must be selected on this page, although radio buttons are used.



(b) Since users may not know the exact amount of electricity they consume, an alternative input is needed to estimate the value from. By tapping on the number of residents living in the building or moving the slider, the value in the text field is updated correspondingly, indicating the effects of the user's changes in real time.



(c) Similar to the electricity consumption, not all users will know their tariff, so they can enter their monthly bill alternatively. Additionally, a checkbox enables them to indicate that they do not know the answer to this question, leading to a default value being used instead. Upon selecting this option, the slider as well as the text field are grayed out.

Figure 16: These figures show different ways how similar or closely related questions can be combined. This can avoid duplicated or unnecessary questions but must be carefully designed to clarify to the user where exactly they should select or enter something.

Gestalt principle of proximity [47], and a line in between to act as a border. Additionally, the default selection of one button per set can act as a cue.

Another situation arises when an alternative input for a difficult question should be allowed. For example, as an alternative to their yearly consumption of electricity, users should be allowed to enter the number of residents in their house if they do not know the former value. The number of residents can then be used to estimate it, in which case the result should be immediately indicated to the user. Figure 16b illustrates

[47] https://www.usertesting.com/resources/topics/gestalt-principles

this case, where the text field and slider are synchronized at all times. Note that this combination has limitations, as at most four residents can be selected. A drop-down menu could be used to enable the selection of a higher number, but it would block the user's view on the rest of the interface, thus increasing the mental load of a direct comparison. Note that the residents are only intended as an orientation here and not of further interest. Users can enter an arbitrarily large consumption, even if it exceeds the estimated value for four residents, so this limitation is accepted here.

Similarly, the electricity tariff might be unknown and can be estimated based on the monthly or yearly bill instead, as shown in Figure 16c. Again, tariff and monthly costs are synchronized in real time, such that users can see the effects of their changes and get a feeling for realistic values. In case the value of the bill is also not known to the user, they can indicate this with a corresponding checkbox. The slider and text field are then grayed out and a default value is used for the computations.

In both of these last two situations, it is important that the user understands the correlation between the possible inputs and that they only need to enter one of them. To clarify this, the secondary input is pointed out to be an alternative by a short sentence. Any remaining confusion should be cleared due to the immediate synchronization between the inputs, but for this to work, the response time of the application must be low, as a tenth of a second delay of the feedback can already cause irritation [28].

3.9. Recommendations

The recommendations are accessible from the dashboard via the tile in the bottom right corner. Figure 17 shows different states of this screen that are displayed in dependence of the user's progress. In all states, the recommended renovation projects are shown in a list where each item contains the project's name, a short description and the main facts investment costs, annual savings in terms of money as well as greenhouse gas emissions and the amortization time in years. A designated start button leads to the detail page of the project, where more information is given and potential project specific parameters can be specified.

The screen on the left of Figure 17 shows the initial state, which includes a hint at the top prompting the user to officiate their refurbishment road map before they start renovating, so they can make use of government funding. This action is highlighted by the coloring of the button, while all other buttons remain unfilled. Once this step has been completed, the hint disappears and the start buttons of projects that are ready to be conducted become primary. Projects that depend on another unfinished project to be done first are not considered to be ready and thus the corresponding button remains secondary.

Once the user has started a project, it appears in a list separate from the remaining recommendations as shown in the second screen in Figure 17. Since users have decided to conduct this project at this stage and have inspected its detail page, the basic facts are not displayed here anymore. Instead, further steps like defining project specific parameters, contacting an expert and completing the project are listed. Completed steps are ticked with a checkmark and a primary button labeled with the next action

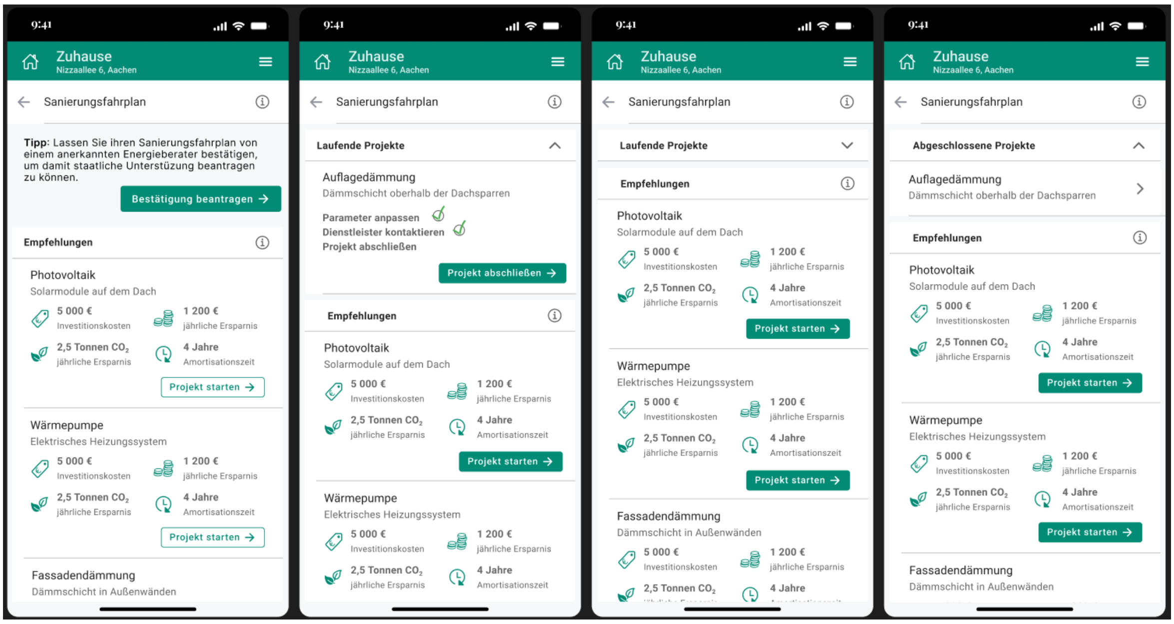


Figure 17: This is the screen for recommendations that is accessed via the button in the bottom right corner of the dashboard shown in different states. The recommendations are listed with their title, a short description and the four main facts indicating investment costs, annual savings in euro as well as CO_2 emissions and the time in years until the investment has paid off. Initially, users are prompted to officiate their refurbishment road map (left), later the running and completed projects are displayed in separate lists that can be collapsed to focus on the remaining recommendations.

suggests to proceed with the process. Note that projects in this list are often in a waiting state because users need to wait for the response of an expert or the construction is in progress. For this reason, the list can be collapsed with the caret on the right, resulting in the third view shown in the figure. Users can focus on the remaining recommendations this way, without the running ones taking up screen space. The same holds for the list of completed projects shown on the right. This list appears when a project has been marked as finished and shows only the title and short description of projects.

3.10. Construction Project

Each recommended construction project has a detail page containing precise information about the costs and benefits it can bring. This page is accessed via the corresponding list item in the recommendations screen described in the previous section. As the three different lists therein suggest, a project can have three different states, being *recommended*, which is the initial state, *running* and *completed*. Figure 18 shows the layout of the project screen for each of these states. Regardless of the state, the

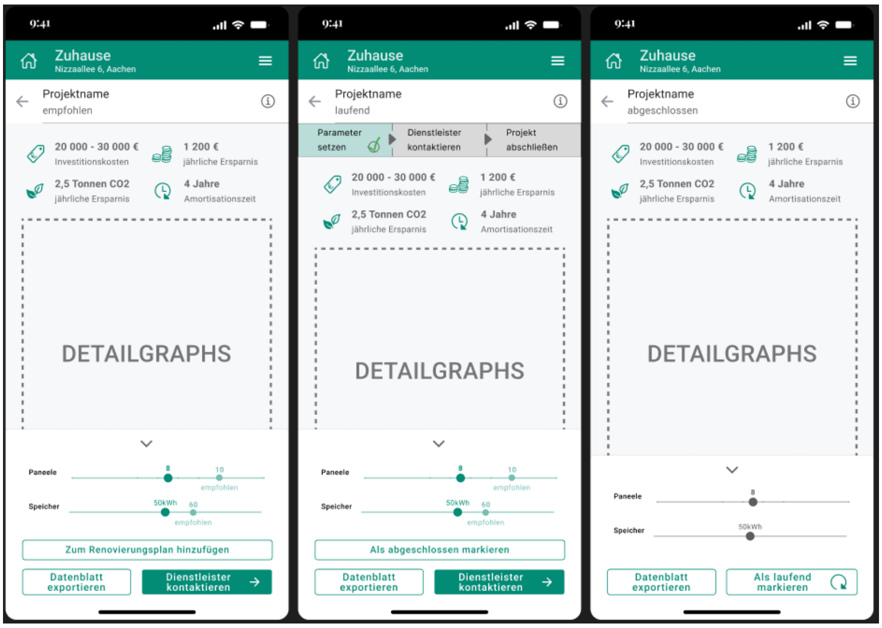


Figure 18: This figure shows the three states of a project's detail page. On the left, it has not been started yet, in the middle it has been added to the refurbishment plan and on the right it has been completed.

detail page always shows the facts and data concerning costs and benefits in concise graphics. This allows the user to inspect these details at any point: In the initial decision and planning phase, during the construction works and after completion of the project. The current state is indicated below the project's title in the header and can otherwise from this screen only be recognized by the changing buttons at the bottom. Initially, these buttons together with the sliders to change the project specific parameters are not directly visible as the user needs to scroll all the way down to the end of the page. This forces them to look at all the detail graphs as computed with the recommended parameter values before they can begin playing around with them. Once they have scrolled down though, the menu containing parameter sliders and buttons is attached to the bottom of the screen, such that users can inspect any of the result plots while changing the parameters. Whenever the parameters are altered from the recommended values, the latter are indicated on the sliders in a light green, such that users can easily return to them. A caret arrow allows to hide the sliders to free screen space and display more result plots at once. Note that the screen must be scrollable so far down that the lowest graphic becomes visible even with the sliders not hidden.
For a *recommended* project, the options menu contains three buttons, allowing the user to mark the project as running, download the datasheet or contact an expert. Thereby, only the latter is marked as a primary button to guide the user towards the project's completion. It leads to the expert screen described in Section B, where users can select a craftsman to commission with the construction. The button on the left prints all data relevant to the project to a PDF, which can be used to consult experts

outside of the application or simply to print the information on paper for documentation. The third button does nothing but change the project's status, assigning it to the collapsable list of running projects in the recommendations screen. This option is given for the case that users want to proceed with the planning and conduction of the project either outside the application or simply at a later point in time. It enables them to indicate their decision to realize the project without starting right away, such that they can inspect some other projects first or continue at a more convenient time. Note that both of the other buttons also change the project's state to *running*, since users likely have decided to carry out the project if they download the data or contact an expert.

Once a project is in the state *running*, the third button allows to mark it as *completed* instead and the progress is shown at the top in form of a bar consisting of three parts that turn green once the corresponding step is completed. The button to contact an expert becomes secondary when it has been used, but it can still be used again in case users want to contact another expert for a better offer or some other reason. When the project is completed, this button as well as the one for completion disappears. A new button allows to mark the project as *running* once again, essentially acting as an undo-button for if the user marked the project as *completed* by mistake. Since a completed project has fixed parameters that can not be changed anymore, the options are deactivated and only displayed in gray. The data sheet can still be exported by the same button as before.

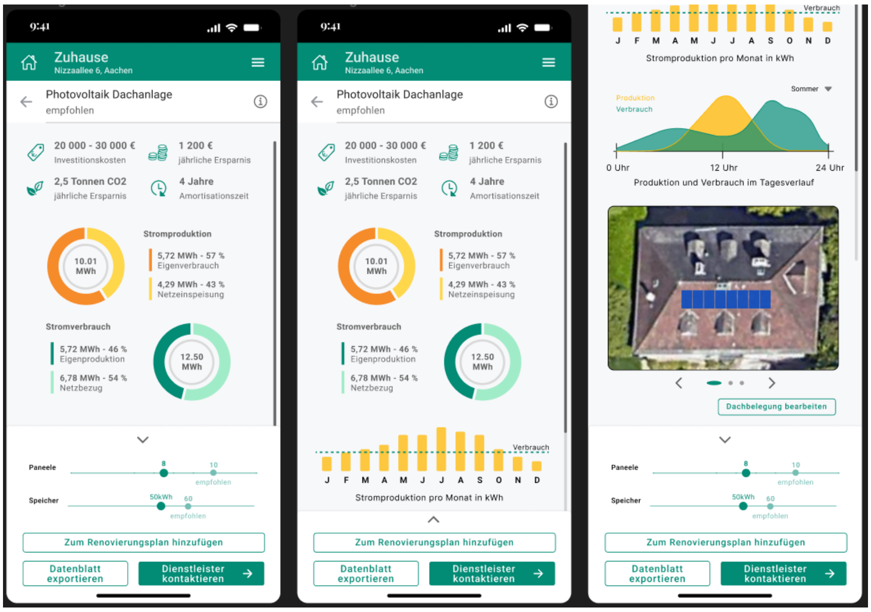
Note that once a project is marked as completed, its effects are taken into account during the computation of the energy efficiency, market value and energy costs displayed on the dashboard. All future projects are recommended based on this new building state.

Detail Page Photovoltaic

The result plots shown on a project's detail page can differ between projects as they depend on their specific properties and goals. Nevertheless, they always align with the template described above and show the four main facts known from the recommendations screen at the top. In the following, the result plots shown on the detail page for a photovoltaic system will be explained. The screen is shown in Figure 19a.

The most important information concerning a new photovoltaic system is likely the amount of electricity it produces, so this is shown in the first graphic. Thereby, a pie chart is used to directly indicate the amount of production the user consumes themselves in contrast to the amount they export to the power grid. The chart is labeled with precise values and percentages on the right, where colors clarify which numbers belong to which part of the pie chart. Below this, the electricity consumption is shown in a similar way, including the share of self-produced electricity and reference power. This enables the user to understand the relation between their consumption and production as they can compare both pie charts and watch how they change while the parameters are adapted.

Next, the monthly production throughout a year is illustrated in a bar graph, where a line indicates the average consumption of electricity. Users can recognize from this



(a) This is the detail page of the photovoltaic project, shown with extended (left) and collapsed (middle) options menu as well as scrolled all the way to the bottom (right). The result plots illustrate the electricity production and consumption in different ways.

(b) In this overlay, the placement of the solar modules can be specified by dragging them from the stack onto the roof. They can be rotated by 90° to place them horizontally.

Figure 19: This figure illustrates the structure of the detail page for a photovoltaic system. It generally follows the template described above but contains result plots specific to this project and additionally an overlay for the positioning of solar modules.

in which time of the year their production will suffice for their own supply and when they will need to purchase additional energy. A closer look at this can be gained from the next graphic, which shows this relation in the course of 24 hours in form of a curve chart. Here, a drop-down menu allows to switch between summer and winter days, as the plot will significantly differ due to the amount of sunshine.

At the bottom, a top view of the house visualizes the placement of solar modules on the roof. Initially, a default placement will be specified, but the user can change it by tapping on the designated button below the image. It opens the overlay shown in Figure 19b, where users can change the positioning of individual modules or drag additional ones from the stack onto the roof. While they can be placed freely in general, modules lock into place next to each other to mimic the scaffolding the modules will be fixated on in reality. Additionally, modules can not be placed in areas that are marked yellow, which result from obstacles like windows or chimneys as well as distance requirements to the edge of the roof. The rotation icon at the top allows to rotate the stack of modules by 90°, so modules can be placed horizontally. When users select a previously placed module on the roof, a similar button to rotate this single module appears in the bottom right corner of the image. The program automatically

slightly moves the module upon rotation in order to integrate it into the scaffolding grid and avoid overlaps with unusable areas. If this is not possible, the overlapping is marked in red (cf. Figure 33). When users tap the confirmation button to close the overlay, any falsely positioned modules are removed from the roof. By tapping the right button at the top of the overlay, users can restore the original placement, which was recommended by the program, at any point.
The left button allows to edit the extents of the roof in another overlay, which is shown in Figure 34. It contains different views of the house that allow editing the relevant dimensions by either moving the border lines by hand or entering measurements directly into the labels, which act as text fields.
The parameters adaptable for a photovoltaic system are the number of modules and the size of electricity storage. Especially the former is restricted due to the size of the roof, so users can only select a number between zero and the maximally fitting number of modules.

4. Evaluation

To evaluate the application, a usability study with a preliminary and a subsequent questionnaire was performed, following the standard practice of a summative user test [33]. One main goal of the study was to see whether users find the usage of the application enjoyable and convenient. Ideally, users should confirm that answering the introductory questions was easy and they intuitively found all areas of the application that were relevant to them. The implicit suggestions of the app should guide them towards the completion of the questionnaires such that they receive meaningful results. Additionally, the study is meant to show whether users feel inclined to follow the given recommendations and proceed with the refurbishment of their house as suggested. An important factor of this is also whether users experience the application as informative and trust the given data to be correct.

4.1. Procedure

Four house owners aged between 35 and 65 years participated in the study. Each of them was provided with a prototype of the SmartRenovation app as a web application on their own mobile phone, such that they were already familiar with the device. An exception was one participant whose device was not available. She used the examiner's phone instead, which is not expected to influence her performance as it has the same operating system and layout as hers. All participants conducted the steps of the study alone and were instructed not to talk to the others about its content or anything related to it before all of them completed their participation. This is important to avoid any form of bias concerning the usage of the app. The test was conducted at the participant's house, which mirrors the expected context of real usage and makes it easier for participants to relax [33].
In accordance with common practice for usability tests, the participants' background and attitude towards the system is queried before the main study begins [33]. First, participants should indicate their age and gender as well as the time they have been owning their house and whether they have refurbished it energetically yet. Then, five statements had to be rated on a scale from one to five, indicating the degree of the participant's agreement. These statements assessed how much experience the participants had in construction planning, whether energy efficiency is currently of importance to them, and whether they wish to install a photovoltaic system. In the end, participants were asked whether they had previously educated themselves about the costs and benefits of a solar system in their individual case, including whether they did this on their own or with help of an expert (cf. List 1). These last two points regarding a photovoltaic system should provide a value of comparison after the study, to see whether the application's recommendations have any impact on the user's intentions. In the second part of the study, participants were instructed to utilize the application, following the approach of a summative user test with a minimally interfering moderator [33]. To allow a subsequent analysis of the process, they were asked to agree to a screen recording of the used device including external sounds

during the app usage. Using the thinking-aloud method, participants were asked to vocalize their thoughts during the study, so any ambiguities or inconveniences could be recognized [12]. The only given task was to use the application, such that the house owners could freely try it out and inspect its functionalities. This way, their reaction to the application's implicit suggestions as well as their understanding of its general usage could be observed. Note that the study utilized only a demo version of the application and not all functionalities are implemented to completion. Nevertheless, the time of free discovery was intended to test whether users would feel inclined to answer the detailed questionnaires and would find the first recommended construction project by themselves. If the user did not end up on the photovoltaic detail page by themselves after 25 minutes of total usage time, they were instructed to begin planning the construction, testing whether they are able to quickly find the respective screen. They should then inspect the photovoltaic result plots and adapt the parameters to their satisfaction before they proceed to contact an expert. The component to specify the module placement on the roof is not implemented in the used demo version. The app usage was terminated when the participant felt they had seen every implemented part of the app, or at the latest after 35 minutes of total usage time. This period of time is expected to suffice for a complete inspection of the app's demo version.
Subsequently, participants were presented with a questionnaire to assess whether they liked the experience and feel inclined to follow the resulting recommendations for their house. In order to derive a usability score, the statements suggested for Brooke's System Usability Scale (SUS) [4] were slightly adapted to the application at hand. Further statements were added to determine whether users found it easy to answer the questions in the app, and whether they feel informed about their options and motivated to renovate after using the app. The question concerning the desire to install a photovoltaic system from the preliminary questionnaire was repeated to allow a direct comparison. Additionally, statements about the participants' trust in the displayed results and how they would rate the application in comparison to similar tools were included. Each of these statements should be rated on a Likert scale from one to five, in accordance with Brooke's scale [4]. In case of the last one, multiple scales were used to make comparisons concerning different attributes such as informative, complex or easy to understand. A complete list of all statements in this questionnaire is given in List 2. Three additional text fields allowed the participants to enter further comments regarding what they specifically liked about the app, what could have been better, and anything else they might want to say.

4.2. Results

In accordance with the three parts of the study, the following subsections will depict the responses to the preliminary questionnaire, observations during the usage of the app, and lastly the Likert scores of the final questionnaire.

Participant Background

In the preliminary questionnaire of the study, all participants indicated that they were significantly included in the planning of their house (M = 4,75, SD = 0,5) and energy efficiency was a moderately important factor thereby (M = 3,5, $SD \approx$ 0,58). The agreement on never having thought about an energetic renovation differed between participants (M = 2,75, $SD \approx$ 2,06) and the statement concerning conducted research about ways to renovate their house was rated rather low (M = 2,25, SD = 0,5). The desire to install a photovoltaic system was rated with 3,75 on average ($SD \approx$ 0,96) and all but one participant informed themselves about the costs and benefits of a photovoltaic system in their individual case. Thereof, one did this by herself and the other two consulted an expert for advice.

Usage Observations

Upon start-up of the app, participants of the study calmly navigated through the onboarding pages and read the information with interest. Some of them made comments that they would be interested in the advertised goals. When they reached the login page, none of the participants recognized the distinction between login and registration at first, so they proceeded to enter their credentials at login, triggering an error message due to the non-existing account. All but one participant then immediately recognized their mistake and switched to the registration tab without any problem. The remaining one selected "Password forgotten" and began entering their e-mail address into the appearing form. The examiner interfered at this point and showed them how to proceed, since the sending of password reset mails is not yet implemented. Three of the participants expressed their general aversion to creating an account right in the beginning.

The participants completed the introductory questionnaire within 9:54 minutes on average (SD = 6:05) and afterwards inspected the estimated results. Thereby, two participants needed less than six minutes to answer the questions, while the slowest one, being less experienced with technology, needed almost 18 minutes.

During the questionnaire, three participants wondered how exact their input data needed to be. They were unsure about the building and property measurements and asked the instructor whether an estimation would suffice or if they should retrieve the precise data from their documents. One participant overlooked the alternatives for the electricity tariff and consumption (cf. Figures 16b and 16c), because they did not read the whole question screen but immediately turned to the examiner for help. After being instructed to proceed with the usage, they however were happy about the alternative options and made use of them. The other participants did this immediately, and the immediate translation between alternatives and requested input was pointed out positively. One participant used the resulting value as an indication and subsequently adjusted it.

While three participants liked the interaction with the map for address input, the last one had severe problems with it. Attempting to deselect the text field and close the keyboard, he accidentally tapped on the map, which led to another address being selected than he typed in. He was confused about this and tried again, but made the

same mistake. When his input was finally accepted, the street name was found in another country, which aggravated him and he just left it that way, thinking it was not relevant for the renovation. A few questions onwards, this led to an error, which he dismissed until the examiner asked him to correct the address. Another participant's address was also recognized in another country at first, but she immediately noticed and corrected it without any problems.
One participant expressed their irritation about the paleness of the ground floor, referring to the deactivated checkbox at the question for the floors present in the building (cf. Figure 15a). They thought that this should be selectable just like the other levels. Two other participants found the graphic unclear concerning the upper floor and attic because their own upper floor has roof slopes, which are not shown in the graphic.
Furthermore, one participant had trouble operating the toggles, as they wanted to slide the knobs when a tap suffices. The same participant was confused over the input of renovations conducted on their house. They asked whether the question referred only to energetic refurbishments or renovations in general and wondered how to indicate multiple renovations. None of the others indicated any renovation.
Arriving at the result pages right after the introductory questionnaire, one participant did not understand how to proceed, because the scrolling changed to sideways instead of downwards. He believed this to be an error and tapped around the screen aimlessly until he scrolled by accident. This made him understand the navigation immediately and he later recalled that he had seen this kind of design with the dots at the bottom previously on another device. He did not seem to remember it from the onboarding screens.
When they reached the dashboard, all participants opened the detail pages first and further investigated the results of the simulations. All of them expressed in some way their doubt about the correctness of the results, especially concerning the market value. However, they admitted that they might have entered false information. After that, three of four participants opened the area to add more data, before they navigated to the recommendations. On the latter page, participants first read the shown key data and then opened the photovoltaic detail page. Only one of them attempted to open another project first, namely the heat pump installation. They stated that this was the most interesting to them. All participants reached the photovoltaic project page without an explicit instruction to plan the construction. They all stated that they did not believe the displayed investment costs for the photovoltaic system were correct. None of them noticed the chevron arrow to open the sliders for configuration of the photovoltaic parameters and one participant did not realize there was the option to scroll down, so the pie charts were the only diagrams she saw.
Only once, the app usage was terminated due to the elapse of 30 minutes, the three other participants stated they were done exploring the app after 16:35 minutes of total usage time on average (SD = 6:07).

Subsequent Ratings

Based on Brooke's SUS, the application reached a mean usability score of approximately 83,125 ($SD \approx 11{,}97$). The most positively rated characteristic was that there

was nothing to learn before being able to use the app ($M = 1$, $SD = 0$), closely followed by its low complexity ($M \approx 1{,}33$, $SD \approx 0{,}58$) and the simple operability ($M \approx 1{,}33$, $SD \approx 0{,}58$). Most other statements of the SUS were rated similarly good, the only exception being the one concerning insecurity about what to do, which reached a mean agreement of approximately 2,67 points on the Likert scale ($SD \approx 0{,}58$).
The introductory questions were overall rated as easy to understand ($M = 4{,}25$, $SD = 1{,}5$), but not as easy to answer ($M = 2{,}75$, $SD \approx 0{,}96$). Technical terms were indicated to be well explained ($M = 4{,}25$, $SD = 0{,}5$) and participants commented that they do not recall there were any. Most of the participants are sure they would recommend the app to a friend or neighbor ($M = 4{,}5$, $SD = 1$).
Participants felt moderately better informed about their options to renovate ($M = 3{,}25$, $SD = 0{,}5$) and did not fully trust the results ($M = 3{,}25$, $SD = 0{,}5$). Their motivation to renovate their house and follow the recommendations of the app was rather low ($M = 2{,}25$, $SD \approx 0{,}96$; $M = 2$, $SD \approx 0{,}82$), but the desire to install a photovoltaic system was rated on average with 4 points on the Likert scale ($SD \approx 0{,}82$). Upon reading the statement, all participants in some way expressed that a photovoltaic system would be too expensive.
None of the participants knew any similar tools, so they were unable to compare the application. In the free text fields at the end of the study, positive points that have been pointed out are the application's conciseness, structuring and layout in general as well as the ease of entering data. Furthermore, participants praised the navigation and clear operability. They liked the color design as well as graphical illustrations and diagrams. One participant also positively mentioned the "(potential) scope". Concerning negative points, one participant pointed out her problems with the input of renovations and another wished for more precise information about recommended renovations. A third one would like a back button in the introductory questionnaire as well as a notice of the privacy policy. The font size at the onboarding screens was pointed out to be too small and participants disliked the account system. In the last free text field, one participant stated her opinion that an application like this would be meaningful.

4.3. Discussion

The score of more than 80 points on average on Brooke's System Usability Scale can be interpreted as a very good to excellent rating and shows that participants were overall satisfied with the experience of the application [3]. This is supported by the positive feedback that was given in the free text field at the end of the study as well as several thoughts that were voiced during the app usage. Although participants had trouble answering some of the questions, this is because the construction year and measurements of the house are facts that are not always at the top of the user's head. Nevertheless, they were able to answer these questions with some time to think. In case of electricity tariff and consumption, the alternative options were considered very helpful.
The navigation and operability of the app were intuitively understood and liked for the most part. During the introductory questions, the chevron arrow was seen as a clear

indication of the direction to proceed in and scrolling as well as directly tapping the arrow was used. The bar on the left was not perceived as a scroll bar and one participant even pointed out that they appreciated this indication of progress. Although one participant did not understand the direction change to sideways at the result screens after the questionnaire, this seemed to be clear for all others. When thinking about negative things to say in the free text field in the end, the respective participant mentioned this problem but stated that it could be easily solved with an indication thereof and dismissed it to the incomplete implementation of the app. To avoid such unclarity, a "Next"-button analogous to the one on the onboarding pages should be added here (cf. Figure 8).

Regarding the implicit guiding of the user, it should be mentioned that participants preferred to look at the detail pages before they pressed the primary button to enter further data. However, three of the four participants immediately followed the suggestion on the energy efficiency detail page to add data in order to receive more precise results. Since the design envisages analogous buttons on the remaining detail pages (which are not implemented in the demo version used for the study), this would also lead the user to answer the majority of detail questions. Besides, the primary button may still have an effect, as three of four participants selected it before opening the recommended measures. While this may be a coincidence, it is a clear contrast to the document page, which no participant opened this early. The primary button thus seems to successfully attract the users' attention.

A weakness of the design is the distinction of tabs on the login and registration screen, as none of the participants realized they needed to change the tab at first. For convenience, the registration tab should be initially selected, because this is the one users will most likely need when they first open the app, and later on they should remain logged in, such that the screen is not shown at all (cf. Appendix B). This was part of the intended design already and not implemented accordingly in the demo version. Nevertheless, users should have noticed that they were in the wrong tab, and thus switch to the other one before attempting to log in. The design should therefore be improved to highlight the current tab more clearly. Additionally, users should only be asked to create an account after receiving the initial results. The requirement of an account before providing any kind of "quick win" can demotivate and drive away users [35]. Three of four study participants expressed their aversion to creating an account and one even stated explicitly that she tends not to do anything where she is required to create an account right in the beginning.

Concerning the introductory questionnaire, it should be clarified to the user that an estimation of the input parameters suffices for the initial computation, so they do not feel obliged to receive their documents or measure anything. While this is ultimately necessary to receive precise results, the introductory questionnaire is intended to quickly provide an impression of the house's state, before significant effort needs to be invested.

Furthermore, three individual question screens should be revised. First of all, there should be a button to trigger the address to be marked on the app, so users do not tap just anywhere and accidentally select another address. Although this only happened for one participant, it led to severe problems and a button can be expected to decrease the risk of this happening significantly, because it gives users a specific place to tap. Ideally, the text field should also offer suggestions of possible addresses while the user is typing, in order to increase speed and convenience.

Secondly, the selection of levels should somehow include the option for an upper floor with roof slopes graphically. One possibility to do this would be to add another check-box for this kind of floor specifically, but there might be a more elegant solution. Implicitly querying this additional information may also allow the initial computation of energy efficiency and energy costs to be more precise, because the smaller net volume to be heated can be taken into account.

Thirdly, the indication of previously conducted renovations should be revised. In the preliminary questionnaire, participants were asked about energetic renovations specifically, which might have been the reason for the irritation about which kinds were of interest in the app's question. Nevertheless, this ambiguity can be easily avoided by rephrasing the question, so it should be clarified. Besides, it should be recognizable from the beginning how to indicate multiple conducted measures. Note that this screen was not implemented in complete accordance with the design, which was earmarked to show all renovations in one screen (cf. Appendix B, Figure 29). Because this led to scrolling issues in the implementation, each additional renovation was displaced to a new screen, so users could only see the option to add another one when scrolling onwards. An implementation conforming to the original design might therefore solve this problem already. However, it should also be mentioned, that one participant did not indicate any renovations, although their partner did, sharing the same house. They thought about it but did not recall any. While the options in the drop-down menu could have helped with this, they did not open the menu and thus did not see the options. In light of this, the query could be improved by showing the available options directly with radio buttons. The selected renovations may then be specified in further questions.

The simulation results were doubted by all participants, which they expressed by comments during the usage as well as with low ratings of trust in the subsequent questionnaire. The average rating of involvement in the planning of their house was high, so participants likely had some expectation of their house's worth, which were not met. Considering the current market situation, building prices are generally high, but the application suggested values of 150 000 € to 350 000 €, which is improbably low. Nevertheless, three of four participants stated in this context that they were unsure whether they entered their data correctly, which appeared like an attempt to argue in favor of the app's computations. Furthermore, participants had informed themselves about the costs and benefits of a photovoltaic system, so they were able to evaluate the values given by the app, which were improbably high with over 100 000 €. Overall, a revision of the simulations to produce more realistic results will probably alleviate the user's doubt significantly.

Participants also did not feel significantly better informed about their options to renovate, which may be related. One of them wished for more concrete information in the subsequent questionnaire, as it is already planned to be given in the complete version of the app. The wish for more information is plausible because only the project page for photovoltaics is implemented so far. The low motivation to renovate in general and to follow the suggestions of the app may be related to this, but presumably results from the high costs primarily. All participants mentioned this to be an issue at some point. This can not be changed by the application, but an estimation of the potential government funding for the recommended measures might help to overcome some reluctance. The desire to install a photovoltaic system increased in comparison to before the app usage by one point on the Likert scale. Since only one participant changed their answer and a Likert scale is not dependable on such small differences, this change is more likely to be a coincidence than an actual effect of the app [39]. Irrespective of this, all participants saw the value of the application, which they showed in the free text fields in the end as well as by comments during the usage. This is also mirrored by the agreement of participants to recommend the app to neighbors and friends. The fact that none of the participants knew any similar tools although half of them have been thinking about renovating their house and the majority informed themselves about photovoltaic systems, confirms that an application like this is needed.

4.4. Limitations

The biggest limitation of the study is that it was performed only with a demo version of the application where not all functionalities were implemented. This relates to the missing detail pages for market value, energy costs and projects besides the photovoltaic installation as well as the missing detail questions and the simulation for the refurbishment road map yielding individual recommendations instead of the predefined set. Especially the latter two points lead to an unrealistic illustration of the app's usage. The data acquisition would usually require significantly more time and effort, which might have a demotivating effect on users. Although this can hardly be avoided due to the requirements of the simulations, the application's effect on user motivation should be tested again once the implementation is complete. Providing more information about the different building characteristics as well as concrete advice on multiple renovation projects may also increase the user's interest and motivation. An important point in this context is also the refinement of the simulations, such that the computation results become more realistic.

Furthermore, the demo version of the app includes several small bugs, which decrease the convenience and pleasure of its usage. In some cases, the waiting time until an interaction takes effect is too long, leading users to believe they need to press the button again. The selection of the building's construction year did not work at all for two users. During the introductory questionnaire, the skipping of unnecessary questions partially leads to weird empty pages and sudden scrolls that may be irritating. None of the participants appeared to be significantly bothered by such bugs, but it is unclear how much they influenced their impression of the app and its design. However, this would have decreased the usability, which still reached a high score.

Another weakness of the study is the small number of participants. Although the system usability scale is considered to yield meaningful results even with few responses, a larger group would be more informative [3] [48]. The more users test the application, the more details to be improved would likely be discovered. Besides, the participants of this study have a personal relationship with the examiner, which might create a bias to give positive feedback. This tendency is often a problem in usability testing and should be taken into account when examining the results, but the design was confirmed to be user-friendly nevertheless [33].

[48]https://blog.seibert-media.net/blog/2011/04/11/usablility-analysen-system-usability-scale-sus/

5. Conclusion and Future Work

In this thesis, the layout and design of an application supporting house owners with the energetic refurbishment of their building was elaborated. Particular attention was paid to the usability for lays in the refurbishment and building sector, such that the average homeowner can effortlessly inform themselves and plan their individual refurbishment on their own. Previously, similar encompassing tools were targeted to experts in the field, rendering them largely unusable for inexperienced people. This work contributes a design for an application to make refurbishment information and planning easily accessible through a simple tool for private homeowners without real estate expertise. The overall structure of the app as well as the appearance of individual screens was carefully designed in accordance with common principles of design. This is necessary to simplify the complex functionalities and large amounts of data that are combined in the app, such that users have a pleasant experience and remain motivated to take action in the refurbishment of their house.

The application is centered around a dashboard giving an overview of the building's state. The energy efficiency, market value and energy costs of the user's house are initially estimated based on a minimal set of introductory questions in order to provide an early benefit for the user. To receive more precise results and concrete refurbishment recommendations, additional data must be entered. The recommendations are given in a list where costs and benefits can be compared, such that users can make an informed decision about which measures they want to realize. Users can immediately contact an expert suitable for the respective task via the app and send them all related information or download the data sheets to make external consultations. The application thus supports users throughout the complete process of assessing their situation, creating a refurbishment plan and realizing the specified measures.

A small user study was conducted to assess the application's usability, credibility and effect on the desire to refurbish. Only a demo version with restricted functionality was available for testing, but the study showed that users were able to answer the introductory questions without any expertise in the area and liked the visual appearance of the interface as well as the usability. Only a few small issues arose that need to be addressed in the further development of the app. A significant weakness is the credibility of the results, as the computed values were partially unrealistic. Participants of the study doubted them but with improved simulations, the application is expected to be credible. The complete version will inform house owners effectively about their options. The app does not seem to significantly motivate users for the renovation, but including an estimation of the potential government funding may improve this.

To conclude, the designed application in its demo version generally satisfies the expectations. The final version is expected to be a useful and pleasurable tool for inexperienced house owners to assess the state of their building and create a renovation plan. To confirm this result, the study should be repeated with a greater group of participants once the implementation of the app is completed. In the following, the tasks for future work will be depicted.

Completion of the App

There are several functionalities that are missing or provisionally substituted in the current version of the app. The correct computation of an individual refurbishment roadmap must be integrated (cf. Section 2.3) and the detailed questions as well as the corresponding area of the app need to be implemented (cf. Section 3.7). Therefore, the input parameters of the standard procedure in the heat demand simulation as well as the complete input of the energy efficiency simulation need to be analyzed to deduce suitable user questions (cf. Sections 2.1 and 2.4). The detail pages for market value, energy costs and all recommended projects should show the respective computation results (cf. Section 3.6) and resulting documents should become available in the designated area (cf. Appendix B). Furthermore, a database of experts should be connected to allow direct consultation (cf. Appendix B).
Once the application is implemented completely, another user study should be conducted to test those elements of the design that are not included in the current demo version.

Improvements of the Design

Although the user study revealed an overall satisfaction with the design, some minor improvements should be conducted. As discussed in Section 4.3, this includes the design of the login screen, the input of the address and existing levels of the house as well as the indication of previously conducted renovations. At the beginning of the introductory questionnaire, the user should be informed that the upcoming questions are meant for an initial estimation and the data can be adjusted later on, so they know they do not need to consult any documents just yet. On the result pages after the introductory questionnaire a "Next"-button should be included.

Extensions of the App

There are some possible extensions of functionality that could be added to the app and may increase its utility. Partially, they simply accelerate or facilitate the usage of the application, others are more difficult to integrate. In some cases, it might be preferable to refrain from the addition to avoid additional complexity.
One possibility to accelerate the process of data acquisition in the detailed questionnaires is to skip the creation of a floor plan. In the current design, the procedure takes a lot of effort and time, because each room must be added individually. This could be avoided by allowing users to upload an existing floor plan instead, but they might not have one. Ideally, the application should incorporate the functionality to automatically create a floor plan based on an analysis of an uploaded video of the building's interior. Using satellite and LIDAR data, it might be possible to immediately derive some information from the entered address, decreasing the number of questions users need to answer. A simple example that can be recognized automatically is the rotation of the roof to assess its suitability for a solar system. Deriving the number of levels or the presence of sun protection is more difficult because top-down satellite images do not suffice for this.
In order to further support users during the process of project completion, several

additional functionalities can be integrated. For example, a calendar may help with the planning of construction works or a to-do list may provide a better overview of upcoming tasks. The communication with craftsmen may be completely included in the app, eliminating the need for external contact. Thinking one step further, the application could allow to share complete houses with other users, enabling partners to work collaboratively or refurbishment experts to inspect the building's parameters directly in the app. In a designated expert mode, more in-depth questions usually derived from other options may be activated to allow perfectly precise results.

A. Appendix A

Market Value

<table>
<tr><th>Input</th><th>Unit</th><th>Description</th></tr>
<tr><td>Type of the house</td><td>Type index</td><td>The simulation expects as input for this parameter an integer of one, two or three, specifying whether the house is detached, a row-house on the edge or a row-house between two houses. In the user interface, these indices are abstracted from and the type is selected from radio buttons with images.</td></tr>
<tr><td>Levels of the house</td><td>String</td><td>The simulation requires one of the following strings, which indicate the levels that are present:
”ke” for basement and ground floor
”keo” for basement, ground and second floor
”enu” for only a ground floor without a basement
”eonu” for ground and second floor without basement
Although the user could select one of these options directly, introducing the abbreviations would unnecessarily complicate the interface. Besides, other simulations require information about the number of floors as an integer. In order to combine these two inputs and at the same time simplify the interface, the user is presented with multiple checkboxes to select the floors that exist in their building (cf. Section 2.1). This way, the respective string as well as the total number of floors can be deduced. Since the number of upper floors is potentially large, selecting each of them with a checkbox might be irritating, so a text field and a plus sign next to the checkbox enable the user to specify it directly or increment arbitrarily.</td></tr>
</table>

Table 6 - *Continued on next page*

Input	Unit	Description
Type of the roof	String	This question targets not only the kind of the roof itself but also whether there is an attic with living area. Similar to the levels, the input is expected to be one of the following abbreviations: • ”dva” for an attic with living area • ”dna” for an attic without living area • ”ffg” for a flat roof or a roof with a flat slope Again, the interface should abstract from the abbreviations. The existence of an attic is already checked by the previous question, so it remains to be asked whether it is part of the living area. This is considered to be equivalent to being heated and thus asked in combination with the basement heating by means of checkboxes.
Size of the floor area	Square meters	Here, the size of the floor area should be given in square meters, where balconies are excluded. This can be easily done with a short text field but is instead calculated from the width and length of the building, which are already queried for the energy efficiency simulation.
Size of the whole property	Square meters	The property size will be entered in a text field as an integer in square meters. In a future version, it might be automatically recognized from the address.
Location	Address	The address is required as state, city, street, house number and zip code. To facilitate the input as much as possible, a short text field with autocomplete is used, where possible addresses are suggested while the user is typing. Upon selecting an option, the specified location is shown on a map, so the user can see whether the input was correctly recognized. Alternatively, the address can be directly selected in the map.
Year of construction	Annual number	The year in which the house was built can be selected directly from a list of annual numbers in a drop-down menu.

Table 6 - *Continued on next page*

Input	Unit	Description
A quality level for each of the nine areas	Integer	The areas outside walls, roof, windows and doors to the outside, inside walls and doors, ceiling constructions and stairs, floors, sanitary facilities, heating system, and other technical equipment need to be classified into five quality levels. For each area, the levels depend on multiple characteristics, described in Table 7. Asking for all of them would result in a large amount of questions, which should be avoided. Instead, users are asked to estimate the quality levels themselves based on the given descriptions. Because this is still a significant amount of effort, the quality is estimated for the initial indication based on the construction year and potentially conducted renovations (see Table 5).

Table 6: These are the input parameters required for the simulation of the market value. The right column explains the purpose and procedure for data acquisition respectively.

Area	Weight	Level 1	Level 2	Level 3	Level 4	Level 5
Outside walls	23%	Timber frame, brick masonry; smooth joint coating, plaster, cladding with fiber cement panels, bitumen shingles or simple plastic panels; no or clearly not up-to-date thermal insulation (before approx. 1980)	single/two-skin masonry, e.g. lattice bricks or hollow blocks; plastered and painted or wood cladding; thermal insulation not up to date (before approx. 1995)	single/two-shell masonry, e.g. of lightweight bricks, sand-lime bricks, aerated concrete blocks; noble plaster; composite thermal insulation system or thermal insulation plaster (after approx. 1995)	Facing masonry, double-skin, rear-ventilated, curtain wall (e.g. natural slate); thermal insulation (after approx. 2005)	elaborately designed facades with constructive structuring (column positions, oriels, etc.), exposed precast concrete elements, natural stone facade, elements made of copper/anodized sheet metal, multi-storey glass facades; insulation to passive house standard
Roof	15%	Roofing felt, fiber cement boards/corrugated sheets; no to little roof insulation.	simple concrete roof tiles or clay roof tiles, bitumen shingles; roof insulation not up to date (before approx. 1995)	Fiber cement shingles, coated concrete roof tiles and clay roof tiles, foil waterproofing; zinc sheet gutters and downspouts; roof insulation (after ca. 1995)	glazed clay roof tiles, flat roof design partly as roof terraces; construction in glulam, heavy solid flat roof; special roof shapes, e.g. mansard, hip roof; above-rafter insulation, above-average insulation (after approx. 2005)	High-quality roofing, e.g. slate or copper, green roof, flat roof that can be driven on; elaborately structured roofscape, visible arched roof structures; gutters and downpipes made of copper; insulation to passive house standard
Windows and outside doors	11%	Single glazing, simple wooden doors	Double glazing (before approx. 1995); front door with non-standard thermal insulation (before approx. 1995)	double glazing (after approx. 1995), roller shutters (manual); front door with contemporary thermal insulation (after approx. 1995)	Triple glazing, solar control glass, more elaborate frames, roller shutters (electric); higher quality door system e.g. with side panel, special burglary protection	large fixed window areas, special glazing (sound and sun protection); exterior doors in high-quality materials
Inside Walls	11%	Half-timbered walls, simple renders/plasters, simple whitewash; filler doors, painted, with simple hardware without seals	solid load-bearing interior walls, non-load-bearing walls in lightweight construction (e.g. wooden stud walls with gypsum board), gypsum planks; lightweight doors, steel frames	non-load-bearing interior walls in solid construction or stud constructions filled with insulating material; heavy doors, wooden frames	Exposed brickwork, wall paneling (wood panels); solid wood doors, sliding door elements, glass doors, structured door leaves	designed wall drains (e.g. pier templates, stepped or curved wall sections); paneling (precious wood, metal), acoustic plaster, fire protection cladding; floor-to-ceiling elaborate door elements
Ceiling constructions and stairs	11%	Wooden beam ceilings ohre filling, trellis plaster; softwood stairs in simple type and design; no impact sound insulation	Wooden beam ceilings with infill, capped ceilings; steel or hardwood stairs of simple type and execution	Concrete and wooden beam ceilings with impact and airborne sound insulation (e.g. floating screed); straight stairs made of reinforced concrete or steel, harp stairs, impact sound insulation	Ceilings with greater span, ceiling cladding (wood panels/cassettes); spiral staircases made of reinforced concrete or steel, hardwood staircase system of better type and design	Ceilings with large spans, articulated, ceiling paneling (precious wood, metal); wide reinforced concrete, metal or hardwood staircase system with high-quality railings
Floors	5%	without coating	Linoleum, carpet, laminate and PVC floors of simple type and finish	Linoleum, carpet, laminate and PVC floors of better type and finish, FLiesen, artificial stone slabs	Natural stone slabs, prefabricated parquet, high-quality tiles, terrazzo flooring, high-quality solid wood flooring on insulated substructure	high quality parquet, high quality natural stone slabs, high quality precious wood floors on insulated substructure
Sanitary facilities	9%	simple bathroom with stand WC, installation on plaster, oil paint, simple PVC flooring	one bathroom with WC, shower or bathtub, simple wall and floor tiles, partially tiled	one bathroom with WC, shower and bathtub, guest WC; wall and floor tiles, tiled to room height	one to two bathrooms with partly two washbasins, partly bidet/urinal, guest toilet, shower at floor level; wall and floor tiles; each in upscale quality	several spacious, high-quality bathrooms, guest WC, high-quality wall and floor tiles (surface structured, single and surface decors)
Heating	9%	individual furnaces, gravity heating	District or central heating, simple warm air heating, individual gas outdoor wall heaters, night storage, underfloor heating (before approx. 1995)	electrically controlled district or central heating, low-temperature or condensing boilers	Underfloor heating, solar collectors for hot water production, additional fireplace connection	Solar collectors for hot water production and heating, combined heat and power unit, heat pump, hybrid systems; costly additional fireplace
Other technical equipment	6%	very few sockets, switches and fuses, no residual current circuit breaker (RCD), cables partially on plaster	few sockets, switches and fuses	contemporary number of sockets and light outlets, meter cabinet (from approx. 1985) with sub-distribution and tilt fuses	numerous sockets and light outlets, high-quality covers, decentralized ventilation with heat exchanger, several LAN and TV connections	Video and central alarm system, central ventilation with heat exchanger, air conditioning, Bussystem

Table 7: This table shows the nine areas that need to be rated in quality levels for the computation of the market value. Each area is assigned a weight that connotes its impact on the overall value. The respective quality level must be chosen by comparing the characteristics of the house with the level descriptions given in this table. [5]

Heat Demand

Input	Unit	Description
Height of the building	Meters	The height of the building is determinant for the amount of heat that is lost through the outside walls, as a greater area can emit more heat. Since the building is not necessarily equally high in all places, an average value should be given here. This can be easily done via a text field, as homeowners probably know the average height of their house or can estimate it.
Number of levels	Integer	The levels are already requested in the introductory questionnaire for the simulation of market value (cf. Section 2.2), such that no additional question is necessary here.
Standard internal temperature	°C	To compute the amount of heat that is necessary for a building, the desired temperature must be known. This depends on the usage of the building, which is assumed to be residential for this application. Therefore, a standard temperature of 20 °C is assumed.
Thermal bridge surcharge	$W/(m^2 \cdot K)$	This additional heat transfer coefficient depends on the quality of the building's insulation. There are four different types that constitute high, standard, damaged or weak insulation. Each level is connoted with a value for the thermal bridge surcharge, but users are not expected to be aware of their level or understand the coefficient. It is therefore simplified to $0.1 W/(m^2 \cdot K)$ per default, which is the least effective insulation. If the construction year of conducted renovations indicates a higher quality of insulation, the value is adapted accordingly.
Air exchange rate	h^{-1}	This parameter denotes the rate at which air in the building is exchanged, which is determent for the ventilation heat loss. The exact measurement is unlikely to be known by users, so they are asked to classify their house in the classes "airtight windows", "medium airtightness" or "significant leaks". Based on this indication the air exchange rate is estimated to be 0.25 h^{-1}, 0.5 h^{-1} or 1 h^{-1}, respectively. This value is immediately inserted into a text field, which also allows direct input by users for more precise simulation results. Prior to the acquisition of this parameter, it can also be estimated based on the construction year, where houses built after 1995 are considered to have airtight windows, those built between 1977 and 1994 provide medium airtightness and all buildings older than that are assumed to have significant leaks.

Table 8 - *Continued on next page*

Input	Unit	Description
Postcode	Five digits	The amount of heat loss to the outside also depends on the usual surrounding temperature, which can be deduced from the location of the building. This is already given in the introductory questionnaire due to its relevance for the market value (cf. Section 2.2).
Net volume	Cubic meters	The volume of the building determines the amount of air it can hold and therefore also affects the amount of heat it can hold. The parameter is optional for the simulation and can be deduced from the size of the living area and the height of the building, so it is not queried.
Room-specific input The following input data is specific for individual rooms of the building and needs to be given separately for each room.		
Standard internal temperature	°C	The desired internal temperature must be known room wise in order to calculate the amount of heating that is necessary to achieve this temperature in each room. For residential usage, which is assumed in this application, the standard temperature is 20 °C, only in bathrooms it is set to 24 °C. Therefore, only the number of bathrooms in the building must be queried. This can be done by simple selection of the correct integer from a drop-down menu.
Room volume	Cubic meters	In addition to the volume of the whole building, the volume of individual rooms is needed to determine the air flow between them. This is deduced from the floor plan, where length and width are already given and only the height needs to be added. To facilitate this process for the user, the height from previously defined rooms is automatically adopted for new rooms. Users can then edit this value if necessary. Before the creation of the floor plan, the average height of levels can be used as a simplified alternative, which is given in the introductory questionnaire.
Air exchange rate	h^{-1}	This parameter is optional to give for each room and will initially default to 0.5 h^{-1}. For a more precise computation, the airtightness can be queried for individual rooms the same way it was done for the overall building, i.e., by means of three radio buttons denoting strong, medium or insufficient airtightness.

Table 8 - *Continued on next page*

Input	Unit	Description
Component-specific input The following input data is specific for individual components of the building and needs to be given separately for each component that is adjacent to outside air, soil or unheated rooms.		
Area	Square meters	To determine the amount of heat that can be transferred by a component, its area is required. For walls this parameter can be directly deduced from the floor plan, since the measurements of rooms are given there. Other components like windows and doors need to be specified for this purpose specifically.
U-Value	$W/(m^2 \cdot K)$	The U-value connotes how fast heat is transferred through a component. Users are not expected to be familiar with this, so it must be explained when queried. It can be acquired from the manufacturer of the component, measured directly, or computed from the indoor, outdoor and the component's surface temperature. All of these approaches are quite effortful for the user but for the most accurate results, these inputs are needed. Nevertheless, the construction year, type and the material of the component can be given alternatively as input to the simulation to estimate the U-value. The type and material of the component should be known to the user and can be directly given upon its creation in the floor plan. Its construction year is assumed to be the same as the one of the whole building, except if a renovation in relation to this component was conducted, in which case the renovation year is assumed.

Table 8 - *Continued on next page*

Input	Unit	Description
Temperature adjustment factor	-	This factor is used to adjust the heat loss of a component to the area it is adjacent to, since the characteristics of that area affect the amount of heat that is lost. If the component is adjacent to outside air, the factor is set to 1, such that the heat loss is not changed. For components next to a heated room or soil, an adjustment factor of 0.3 is used. If the component is adjacent to an unheated room, the adjustment can be estimated to 0.5 or more precisely determined based on specific properties of the adjacent room, such as whether it has walls to the outside, is located in the basement or contains windows and doors to the outside. This information can largely be deduced from the floor plan, such that no further question is necessary for this parameter.

Table 8: These are all the parameters needed for the simplified computation of the heat demand, which disregards the ventilation heat loss. Since the heat demand is not displayed immediately after the introductory questionnaire, querying this information in the detailed questions suffices. However, some of them can be deduced from data that has been given before, such that no further question is needed. The table discusses the data acquisition of each parameter in the right column.

Photovoltaic

Input	Unit	Description
Type of house	String	It is important to know whether the building is detached or a row house and in case of the latter whether it is on the edge of the row or in the middle. This determines the distances the photovoltaic system needs to have to the neighboring building. Since this information is also relevant for the market value, it is already planned to be requested in the introductory questionnaire by means of single select radio buttons (cf. section 2.2).
Monument protection	Boolean	Since buildings under monument protection can not be legally equipped with a photovoltaic system, this question is mandatory and should be asked in the introductory questionnaire. It can be answered with a simple toggle, which the user needs to activate if monument protection is given. In this case, further questions regarding photovoltaic can be skipped, since an installation is not eligible. Thereby, questions that are also relevant to other simulations should naturally still be asked.

Table 9 - *Continued on next page*

Input	Unit	Description
Building owner	Boolean	Photovoltaic systems can only be installed by the owner of the house, so this needs to be verified in the simulation. However, the SmartRenovation app is specifically targeted to house owners, so the ownership is not explicitly queried. However, users are informed about this requirement when they attempt to contact a craftsman for a construction project.
Solar system	Boolean	To assess the demand, the user should indicate whether they already have a photovoltaic system. This is done by activation of a corresponding checkbox in combination with the indication of an electric car, which influences the electricity consumption (cf. next row). If a solar system is present, its construction year and electricity production need to be given, which is done via a drop-down menu or a text field respectively. The production can alternatively be estimated based on the year and number of modules. In case multiple houses have been recognized at the given address, users should also select the house or all houses which carry solar modules. All of this is done in the introductory questionnaire.
Current electricity consumption	kWh	In order to compute the degree of independence and the percentage of private consumption of the energy yielded by a potential photovoltaic system, the user's energy consumption must be known. Ideally, this information should be given directly in kWh by means of a short text input, but for ease of usage, the interface also allows the user to select the number of people living in the house instead. The consumption can be estimated based on that, while other consumption factors such as a heat pump or an electrical car should also be taken into account. For the heat pump, no additional question is necessary, as the heating system is already queried for the indication of energy efficiency. The usage of an electrical car can be indicated by a checkbox in combination with the existence of a previous photovoltaic system. Since this data is also relevant for the initial indication of energy costs, it is queried in the beginning.

Table 9 - *Continued on next page*

Input	Unit	Description
Current electricity tariff	Cent per kWh	How much the user currently pays for electricity is relevant for the computation of financial benefits of a photovoltaic installation. Like the consumption of electricity, it is queried in the introductory questionnaire due to its relevance for the energy costs. Users should not be required to look it up when starting the application though, so it is entered via a slider restricted to common values for the area and users can enter their monthly or yearly electricity bill as an alternative. The question also contains a checkbox labeled ”I do not know”, which leads to the tariff being set to a default value for the initial indication. In this case, the question is later repeated in the detailed questionnaire, where the checkbox is omitted.
Roof tiles	Image selection or upload	The type of roof tiles is necessary to determine the kind of construction to be used to mount the photovoltaic modules to the roof. Possible options here are for example shingles, plain tiles, slate or trapezoidal sheet metal. Users can enter this information by selecting one of the predefined options, where each option is clarified with a picture since users might not know what the correct material is called. If the right material is not given, users can upload a photo of their own roof. This query is not relevant for the initial indication and will therefore be asked only later in the detailed questionnaires.
Location	Address	The simulation requires the exact location of the house in order to determine the roof's suitability for solar panels. The address is queried in the introductory questionnaire as part of the basic information needed for the initial indications, but it may not be precise enough. In case there are multiple buildings recognized at this address, they are marked with polygons on the map and the user is asked to select the house they would install a photovoltaic system on.
Roof extends	Rectangle size and location	To allow the more detailed planning of the solar panels, the extends of the roof must be measured. The database of LANUV is enhanced with lidar data and 3D models to suggest an outline with cutouts for chimneys, roof vents and windows. The user needs to confirm, adapt or delete them. This is detailed information and is not required to be asked in the beginning. In the detailed questionnaire, the user can mark and correct the extents in an interactive image.

Table 9 - *Continued on next page*

Input	Unit	Description
Meter cabinet	Image upload	To decide whether the meter cabinet is sufficient for a photovoltaic system or whether it needs to be replaced or extended, its current state must be assessed. Users can not be expected to be familiar with the components, so specific questions would be difficult to answer. Instead, a photo of the cabinet is uploaded and analyzed automatically. Again, this is a detailed configuration irrelevant to the initial indication.
Roof coverage	Graphical representation	The number of modules and their exact placement on the roof needs to be configured, but it does not regard the current situation of the building but rather the way the project will be realized. This input is therefore not requested during the regular questionnaires but can be selected on the detail page for the photovoltaic project, where the resulting costs and benefits will be directly displayed. Individual modules can be positioned in an interactive image of the roof, which is supported by a magnetism effect pulling them in place to form a grid for a scaffold. Areas that are unusable due to distance regulations towards obstacles or the roof's edge, are marked and can not be covered.
Battery storage	kWh	The size of the battery storage to be installed also belongs to the parameters of realization and is configurable on the photovoltaic project page. It is specified by means of a discrete slider with intervals of 2,5 kWh.

Table 9: This table lists the input required for the simulation of a photovoltaic system. In the right column, the acquisition of this data is discussed.

Combustion Air Supply

Input	Unit	Description
Type of the house	String	The supply air flow depends on whether the building is a single- or a multi-family house. A residential usage is assumed and other information about the type of building is not necessary. Since this information is also relevant for the computation of energy efficiency, it is requested in the introductory questionnaire. Therefor, single select radio buttons are used.

Table 10 - *Continued on next page*

Input	Unit	Description
Construction year	Annual number	The year of construction will be asked for by a drop-down menu in the introductory questionnaire as it is relevant for several of the integrated simulations.
Number of levels	Boolean	Here it is only relevant whether there is more than one level. This information can be extracted from the exact number of levels, which is required for the initial indications.
Ventilation type	Boolean	This parameter specifies whether the ventilation is realized with natural air exchange only or if a technical system with fans is applied. It determines the way the combustion air supply is computed. The query is formulated such that users only need to activate a switch if they have a technical system installed and otherwise leave it deactivated.
Renovations changing the air permeability	Boolean	The simulation only requires a Boolean parameter here. A significant change in air permeability is considered to result from an exchange of at least one third of the windows, sealing at least one third of the roof or adding outdoor air passages. Users could be asked directly whether such renovations were conducted, but this information can also be deduced from the complete list of renovations that is given in the introductory questionnaire for the computation of market value and energy efficiency. Therefore, no additional query is needed.
Utility room	Selected room	The utility room is the room, where the main components of the heating system are located. For the simulation its volume, a Boolean whether it has a door or a window to the outside, the number of outdoor air diffusers in it and the seal of all doors to the room must be given. Since these questions or variations need to be answered for all rooms, they are treated as room-specific questions (see below) and will be asked after the creation of a floor plan. The utility room can simply be selected from this floor plan.

Table 10 - *Continued on next page*

Input	Unit	Description
Nominal power, type and fuel of the heating system	kWh, indices for type and fuel	These pieces of data need to be entered in order to deduce the combustion air requirement. Especially the first one is unlikely to be known by heart, but these inputs are mandatory for the computation. They are queried during the detailed questionnaires, by a text field in case of nominal power and otherwise by radio buttons enabling the user to compare the options. The latter are explained in case they are unclear and the indices are abstracted from.
Fireplaces and their rated power	Selected room, type of fuel, kWh	In addition to the main heating system, all other fireplaces such as gas boilers, oil heatings and fireplace stoves need to be specified including the type of fireplace, their rated power and their location. Again, the latter can be given by selection from the previously created floor plan. The type is then selected out of a set of predefined options given in the form of radio buttons and the nominal power has to be given as text input.
Number of rooms	Integer	Since all rooms are instantiated in the floor plan, the overall number can be extracted from there.

Room- and component-specific input

The following input data is specific for individual rooms or components of the building and needs to be given separately for each room or component respectively.

Title for the room	String	The room title is mainly used for the sake of a better overview and understanding of which information relates to which room. Since users might be unwilling to think of a name, a standard title is automatically generated from the usage type of the room and the number of previously defined rooms with this usage. The user can then edit the title as they wish.
Usage type	Type classification	This is chosen out of a predefined set of possible types, including utility room, office, dining room or bedroom. The field is set upon the creation of a room in the floor plan as it is basic information and required for the generation of a title. This leads to a limitation of the space available for the field, so a drop-down menu is used although radio buttons would be more suitable due to the unknown set of options.

Table 10 - *Continued on next page*

Input	Unit	Description
Volume	Cubic meters	The size of the room determines its capacity of air. Since the length and width of each room can be extracted from the floor plan, the user only needs to enter its height, then the volume can be computed automatically. This way, users do not need to compute anything themselves.
Existence of a door or a window to the outside	Boolean	Since a gateway to the outside can provide a lot of combustion air, windows and doors must be indicated for each room. Their size and number are not relevant here, only a Boolean is required. Users could simply activate a checkbox to answer this, but it can also be extracted from the floor plan.
Number of outside air diffusers	Integer	Outside air diffusers are specific construction parts that are installed in many buildings to support free ventilation. They need to be quantified for each room in order to compute the combustion air supply. This is done by a simple dropdown menu, since the options are clear.
Existence of a door towards the utility room	Boolean	This Boolean value has to be given for each room except the utility room itself. Similar to the existence of gateways to the outside, this could be indicated by a checkbox, but the effort for the user can be minimized by extracting the rooms adjacent to the utility room from the floor plan.
Seal of the door	Seal classification	For doors towards the utility room or to the outside, their seal must be indicated. This is done by selecting the type of door out of a set of eleven predefined options, which include for example a permanently open gateway, a combustion air opening of at least 150 cm cross section, or a door with a three-sided circumferential seal. The simulation can deduce from this information how much air is leaking through the respective door. Since these are multiple options that are not previously known to the user, radio buttons are used for the selection.

Table 10: These input parameters are necessary for the simulation to confirm a sufficient supply of combustion air for the installed heating system and potentially additional fireplaces. The right column describes how they are acquired.

Energy Costs

Input	Unit	Description
Electricity consumption	kWh	The consumption of electricity should ideally be given in kilowatt hours per year, which can be done by a short text input. However, users likely do not know this by heart, so during the introductory questionnaire, the interface allows to indicate the number of residents in the building as an alternative. The consumption can be estimated on this basis, where one resident is considered to consume roughly 1.500 kWh, two residents together 2.500 kWh, three 3.500 kWh and four 4.250 kWh. Nevertheless, the precise individual value from the user's electricity bill should be entered later on.
Electricity tariff	Cent per kWh	The electricity tariff should be optimally given by the working price per kilowatt hour, but users may not know this. A range of possible values can be predicted based on usual prices and displayed on a slider, which facilitates the selection as users might be able to estimate whether their tariff is comparatively high or low. Nevertheless, the monthly or yearly billing value can be given as an alternative. The working price is then calculated by transforming Equation 5 and indicated to the user immediately. For further simplification, a checkbox labeled "I do not know" allows users to skip this question in the introductory questionnaire. The tariff is then estimated for the initial indication and queried again in the detailed questionnaires.
Electricity base price	Euro	The base price connotes the fixed monthly costs independent of consumption. It is added to the consumption-based costs to receive the overall annual costs and should be indicated in a slider that is limited to realistic values, such that users can immediately get an indication of the price class they are in. However, since users are unlikely to know this parameter by heart, it is initially estimated based on common prices.
Type of heating	String	The kind of heating system is relevant for the estimation of heating costs and can be selected with single select radio buttons, where the options are gas, oil, district heating and a heat pump.

Table 11 - *Continued on next page*

Input	Unit	Description
Fuel consumption	kWh	The energy consumption for heating can be indicated by a short text input of the consumed kilowatt hours in the user's preferred time period, either monthly or annual. Alternatively, after the user has indicated the type of heating system they have installed, they can enter the number of liters, kilograms or cubic meters they consume. The resulting kilowatt hours can then be computed in dependence of the respective energy source [15]. For the initial indication, the input of the exact consumption is skipped, because users are not expected to know their consumption by heart. Instead, the costs are calculated by multiplication of the heated area and a default price per square meter, which is assumed in dependence of the energy source.
Heating tariff	Cent per kWh	Like the electricity tariff, the tariff for heating is queried by means of a slider to indicate the working price per kilowatt hour, but only in the detailed questions. Initially, a default value is assumed.
Heating base price	Euro	Just as for electricity, the base price is set to default value initially and later queried with a slider of probable values.
Warm water consumption	Liter	The warm water consumption can usually be measured with a heat meter or even read from a hot water meter if present. Both options are too much effort for the introductory questionnaire, so a default value in dependence of the number of residents is initially assumed. In the detailed questionnaires, a pop-up can be opened on the question's screen, showing an explanation of how to acquire one's individual consumption. The value is entered in a text field, but there is also the option to indicate via a checkbox that neither a heat meter nor a hot water meter is present. The user is then asked to estimate how much warm water a resident of their house uses on average per day, so this amount can be substituted for the default value in the formula. Since the amount is hard to estimate accurately, users can select from predefined intervals labeled as very low, low, medium, high and very high consumption.

Table 11: Here, the input parameters for the computation of energy costs are listed and explained. Since the costs should be computed for the initial indications upon start up of the app, all parameters need to be queried in the introductory questionnaire or substituted by a reasonable estimation.

B. Appendix B

Login

Figure 20 shows the two variants of the login screen, which is displayed after the onboarding. Since the app has just been installed, the user likely has no account yet, so it is more reasonable to show sign up first instead of sign in. This is also the usual procedure in most applications. The user can switch to login by tapping on “Sign In”, so the two variants are essentially combined like tabs. For tabs, it is important that they are similar and provide different views of the same context [49]. Both requirements are given here, as the layout remains the same and in both tabs, users can type in their email and password. The tab labels clearly indicate the content of both tabs and the selected one is marked with color. Users can proceed by tapping on “Create account” or “Login” respectively, or make use of their Apple or Google account for more convenience.
Once the user has logged in, they should stay logged in, such that these pages are not shown again, except if the user purposefully logs out of their account.

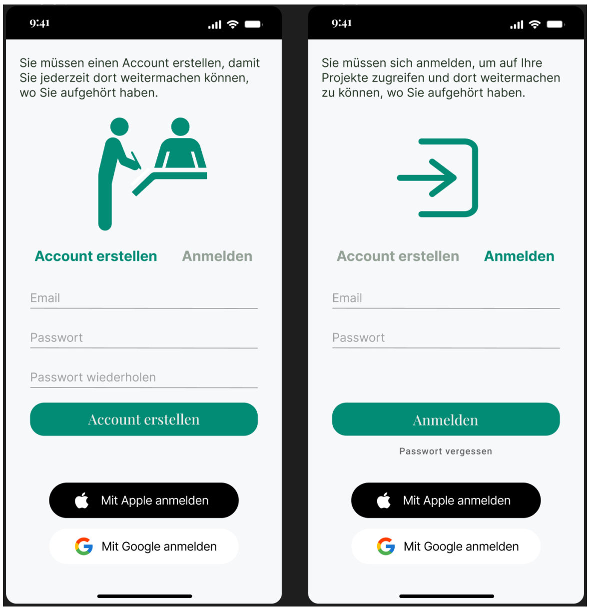


Figure 20: These screens allow the creation of an account of SmartRenovation or the login to an existing one. An account is necessary to store the user input and information about the building to be renovated and run the simulations on the server.

[49]https://www.nngroup.com/articles/tabs-used-right/

Introductory Questionnaire

As described in Section 3.3, an introductory questionnaire is traversed when the user opens the application for the first time. This consists of a limited set of questions that are needed to compute the first estimation of market value, energy efficiency and energy costs. Figure 21 shows some exemplary question screens. The first one contains the heading "Let's get started!", in order to indicate the beginning of the actual app usage and to activate the user. After the previous screens just gave some information and prepared the necessary account, it is now the user's turn to answer questions. Other than that, each question screen is constructed of the same components: In the center or slightly above, the question is written. Below that, some kind of input field is given, where the user can enter the answer to the question. In the exemplary questions of Figure 21, these fields are given in the form of a short text field, a text field with a map and a drop-down menu. In the following, the different input fields will be referred to as different types of questions, which will be further discussed in Section 3.8. The questions themselves are chosen based on the necessary simulation input described in Section 2 and then matched to a suitable type.
When the user has gone through the whole questionnaire and scrolls down from the last question, they are congratulated on finishing the introduction as shown in Figure 22. A countdown indicates the amount of time remaining for the computation of mar-

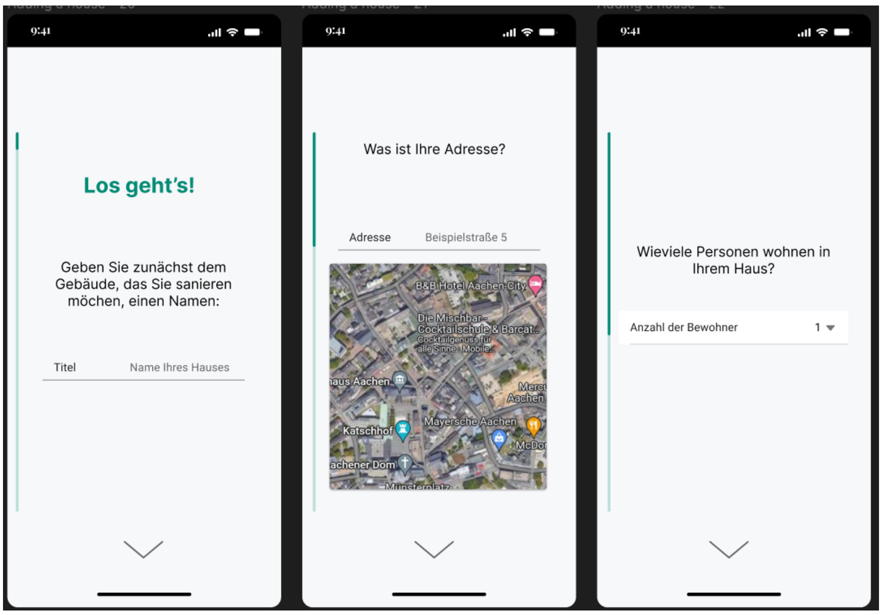


Figure 21: These are three of the questions that are shown in the initial questionnaire, which must be answered before any information can be computed and displayed on the dashboard. The first question contains the heading "Let's get started!" to indicate the start of the application usage to the user, since the previous screens were only preparatory. Other than that, the general layout is the same for each question.

Figure 22: After the user has answered all questions of the introductory questionnaire, the left one of these screens indicates the completion and the number of seconds to wait until the computation results can be displayed. Once the time is up, the screen switches to the one shown on the right here, where the user is informed that the upcoming results are solely estimations. The chevron arrow shows that the next page can be scrolled to.

ket value, energy efficiency and energy costs. Once the computation is done, users are informed that the results are only estimations and further input will be necessary for more precise results. The same chevron arrow as before then enables the user to scroll down towards the result pages.

Result Pages

There are three result pages shown, one for each of the three main results energy efficiency, market value and energy costs. They mirror the areas advertised by the onboarding pages, which is highlighted by organizing them in the same way: They are depicted as side by side and can be navigated by scrolling accordingly or by tapping on the respective dot at the bottom. Again, each of the dots represents one page and the one for the currently displayed one is marked with green color and a bigger size.
On each of the pages, there is a heading at the top and the most important information, i.e., the estimation of the energy efficiency class, the market value or the yearly energy costs respectively, is highlighted in the center of the screen by a colored sphere. In case of the latter two, the sphere is kept in a light green, which has significant contrast to the other colors to be remarkable but is still soft in order to not pierce the eye and make everything easily readable. In case of energy efficiency, the color of the sphere is matched with the computed efficiency class according to the official scale that is displayed beneath it. This provides some implicit feedback to the user whether they have a high or low efficiency, as the shade of green or red indicates the quality. The

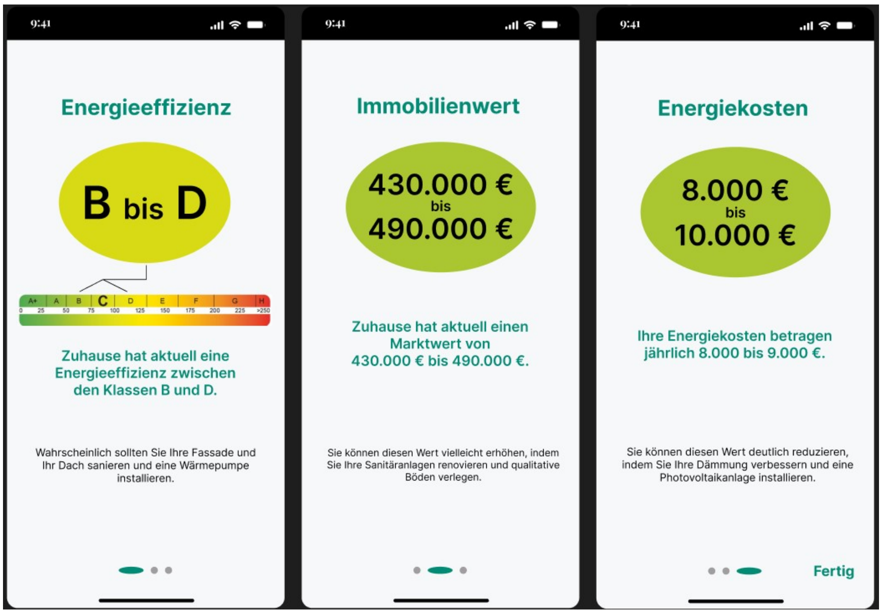
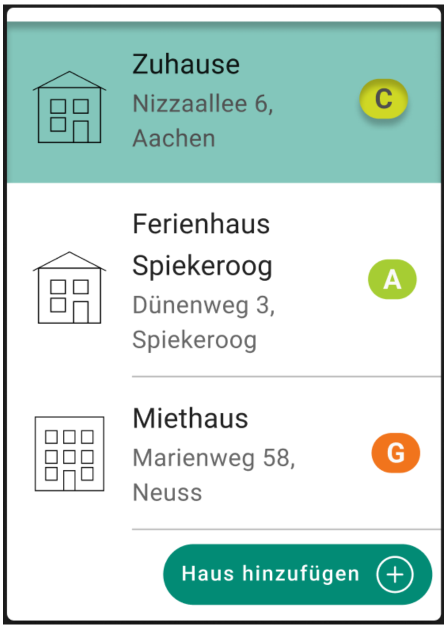


Figure 23: These pages indicate the estimation result after the user has answered all questions in the introductory questionnaire. They mirror the areas advertised in the onboarding pages and are therefore also depicted as side by side and represented by the three dots at the bottom of the screen.

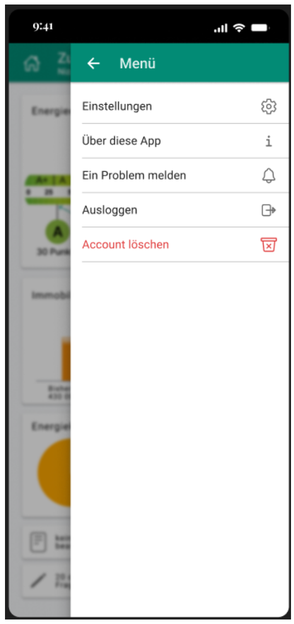
red color of lower efficiency classes can signalize a need for action.
Directly beneath this central indication, each page contains a short sentence explaining it, i.e., the computation results are summarized in words to ensure a right understanding of the letters or numbers shown in the sphere. Additionally, potential measures for the improvement of the respective area are given below. This provides a first idea of what the user can do, such that they get valuable information for the further procedure early on.
On the last page, there is a button labeled "Done" in the bottom right corner of the screen, which finalizes the introductory questionnaire and leads to the Dashboard. There the user can look at the computation results more closely, but ideally, they should enter more data such that a detailed refurbishment road map can be created for their individual case. This is pointed out to the user by an additional screen that is displayed only this one time before the dashboard. Its headline asks "What's next?" and a short text explains that additional data needs to be entered to produce specific recommendations for the renovation. The user can acknowledge this by pressing the "Continue"-button, which then transfers them to the dashboard.

Dashboard Menus

On the left side of the dashboard's header, the house icon allows to open an overlay showing all houses added to the application so far. The user can select one and also add more, as shown in Figure 24a. The batch next to each of the house titles indicates



(a) This overlay is displayed upon tapping on the house icon in the header of the dashboard and can be used to switch between multiple houses that have been registered to the application. The list indicates for each house the building type, the title chosen by the user, the address and the current energy efficiency class. The button at the bottom allows to add another house.



(b) The main menu displayed here is shifted into view from the right edge of the screen when the menu icon in the upper right corner is tapped. It provides basic options like app settings, information about the application and logout.

Figure 24: These two menus can be opened from the main header that is displayed in every area of the application. Thereby, only the main menu shown in Figure 24b can be accessed from anywhere, while the house selection (Figure 24a) can only be accessed from the dashboard. From any other screen, the corresponding icon functions as a home button and leads back to the dashboard.

the current efficiency class of this house through the corresponding letter and also the color imitating the official energy efficiency scale. Note that the color code does not exactly match the colors of the scale. They were slightly adapted in order to ensure the readability of the enclosed letter while avoiding too striking colors. The batches enable the user to implicitly understand the state of each house, but tapping on them also opens another small overlay explaining their meaning in a short sentence, so the user is sure to understand. Displaying the title and address of the house in the header makes sure that the user can always recognize which house they are currently working on and avoids any confusion about which data to enter.
Furthermore, the main menu shown can be opened via the sandwich icon on the right

side of the header. This is accessible from any screen of the app. Figure 24b illustrates how the menu is shifted in from the right edge while the rest of the screen is darkened and blurred again. It offers the usual options of a main menu, including app settings, information about the app, reporting a problem, logging out from the account and deleting an account. They are simply listed below each other and each of them is symbolized by a suitable icon. For example, the settings are represented with the cogwheel commonly used for this purpose.

Refinement of the Detail Pages

As mentioned in Section 3.6, the detail pages allow to traverse a questionnaire specific to the corresponding simulation, such that the results can be refined as soon as possible. At the end of such a questionnaire, a loading screen is displayed until the computation is finished. The user is congratulated for the completion of the questionnaire and informed how much longer the simulation is running. They can return to the dashboard in the meantime if they wish to do so, but the simulations are optimized to finish within a few seconds. When it is done, the screen immediately changes to a result

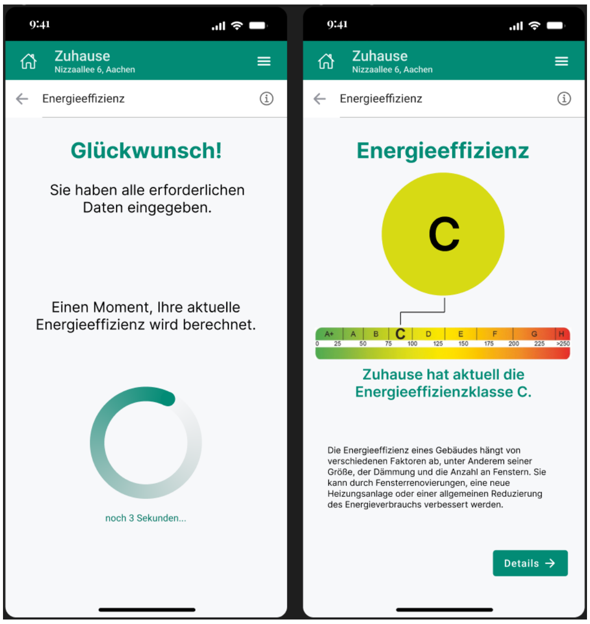


Figure 25: These screens are displayed after the user has answered the detailed questionnaire for energy efficiency. The left one congratulates them on the completion and shows a countdown until the computation of results finishes. It then switches immediately to the screen shown on the left, where the precise efficiency class is indicated. The more elaborate detail page of energy efficiency can be accessed via a primary button. For market value and energy costs, analogous screens are shown during the transition from their respective questionnaire to the detail page.

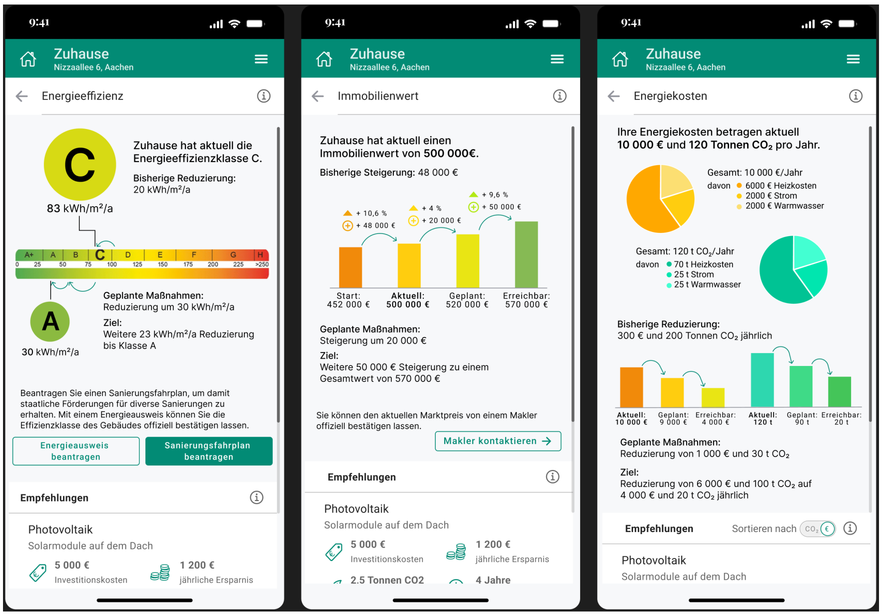


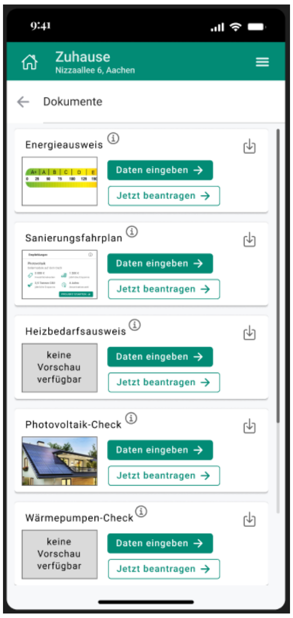
Figure 26: After all detailed questions have been answered, the detail pages provide more information than the initial estimation. This image shows all three of them at a stage of the application usage where the user already conducted a few renovations and has planned more. In addition to the current value and the overall achievable one, the graphics now show the initial value before any renovations as well as the intermediate value that will be achieved by those renovations planned so far. The user is encouraged to plan and execute further measures and at the bottom of each page, suitable projects are recommended.

screen similar to the ones that were shown after the introductory questionnaire. They differ only in the missing information about the results being an estimation, since they are now computed precisely. Instead, a short text informs about influencing factors of the result and how it might be improvable. Figure 25 shows these two screens on the example of energy efficiency. The respective screens for market value and energy costs are analogous, although there is no scale for these areas but just a green sphere like before for the estimated results. The button at the bottom leads to the updated detail page. Figure 26 shows the detail page of each of the three areas after the detailed questions have been answered and the user has conducted some renovation measures. The scale for energy efficiency, the bar graph for market value and the pie charts for energy costs that were already shown before, contain more precise values. They are also enriched with further information about the effects that completed renovations have achieved and planned measures can bring. Therefor, on the energy efficiency page, additional arrows point from the initial efficiency to the current as well as from there to the efficiency that can be achieved when the planned measures are executed. On the market value page, two more bars are displayed to account for the intermediate values. Arrows between these bars are labeled with the respective change of the values

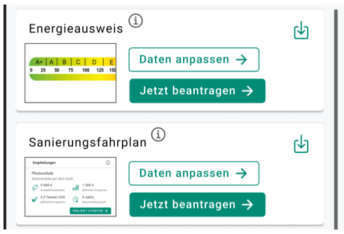
given in percent of the previous value as well as in euro. The detail page for energy costs is extended with bar graphs for the monetary costs and emissions that show the development of these values similar to the market value. The units are thereby displayed with different colors to avoid any misunderstandings. On each of the detail pages, a short text below the graphic informs the user how many further measures are needed to achieve the maximal efficiency, maximal value or minimal costs respectively and how many of those are already planned. This is meant to motivate the user to proceed with the recommended renovations, which is underlined by the encouraging appeal "Go ahead!". In case the user has not planned any measures yet, the information about planned renovations is not displayed, i.e., neither the intermediate arrows and bars in the graphic nor the respective sentence below. This is because the values would equal the current one and not provide any additional information.
Below this, the pages energy efficiency and market value contain once again the buttons to request an energy certificate, a refurbishment road map or contact a realtor. Tapping on any of these buttons does not trigger any warning to appear anymore but leads directly to the page to contact the respective expert. The button for the refurbishment road map is marked as a primary button at this stage since the information required for the creation of this document has been acquired, so the user is incited to confirm it by an expert in order to receive government funding.
At the bottom of each of the detail pages, a list of recommended renovations is given. The design of this list complies with the one on the construction page described in Section 3.9, but its content is limited and ordered according to the page it is displayed on. I.e., on the energy efficiency page only those renovations are listed that have an impact on energy efficiency and they are ordered by the size of the impact. On the market value, only those renovations increasing the building's value are shown and they are ordered by the amount of this increase. On the energy costs page, the recommendations can be ordered by the annual savings of CO_2 emissions or by the financial savings they entail, which can be configured by a switch in the header of the list.

Documents

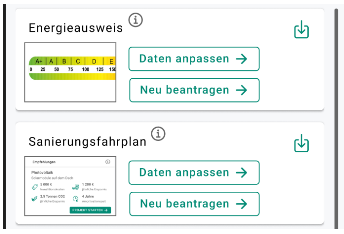
Via the upper tile at the bottom left corner of the dashboard, the user can navigate to the document screen illustrated in Figure 27. It lists various documents that can be created within the application or officiated by experts. These include among others the energy certificate, the individual refurbishment road map and the certificate for heat demand. The former two can alternatively be managed from the detail page of energy efficiency (cf. Section 3.6), in which case their status is updated accordingly on this screen.
Each of the documents is indicated by a tile consisting of the following components: At the top, the title of the document is written. An info icon next to it allows to open an overlay that explains the content and purpose of the document. Below a preview image either mimics the appearance of the document or symbolizes its purpose. E.g., in case of the energy certificate, a part of the official efficiency scale is shown, which



(a) This first stage is displayed when there is still data missing that is needed for the creation of documents. Through the coloring of the buttons, the user should be incited to enter the missing data.



(b) Once the necessary data has been added, the documents are automatically created and can now be downloaded or sent to an expert for officialization.



(c) This last version is displayed when the documents have been created and officiated. It still allows to edit relevant data or request a new officialization.

Figure 27: The document page allows users to enter data specifically needed for certificates like the energy certificate of the official refurbishment road map. Afterwards, these documents can be downloaded here and experts can be contacted to confirm the documents officially. The corresponding buttons on this page change in priority depending on the current stage of the documents.

the user is familiar with due to the display on the dashboard. These images provide a visual cue of what to expect in each document, such that users can decide whether they want to acquire them. The latter can be done through the buttons on the right, one of which leads to the questions relevant to the respective document, while the second one allows to contact an expert who can issue the document officially. Initially, the first button is primary and the latter secondary for all documents as it is shown in Figure 27a. This is because the data relevant to the documents has not been acquired yet, such that no preliminary version can be created by the application and an official issue would be a great effort for the expert. The user is made aware of this circumstance by a pop-up if they select the request button, but they can proceed to skip the data acquisition if they wish to do so. Furthermore, each tile encompasses a download icon that can later be used to save the preliminary document created by the application locally. Initially, it is grayed out since there is no document to be downloaded yet. The user is informed about this in a small pop-up window if they tap on the icon.

Once the required data has been entered, the label of the upper button changes to "Edit data" and it becomes secondary. Instead, the request button below is marked as a call to action as shown in the example in Figure 27b. This should incite the user to contact a suitable expert to officiate the document so it can be used to request government funding or prove the characteristics of the building. The button leads to an expert selection screen (cf. Section B), where the user can choose an expert in the area to contact. The preliminary document is then automatically attached to the message. Another change from the initial version is the coloring of the download icon, indicating that the document has been created and can be downloaded.
Figure 27c illustrates the third stage of the document tiles, where neither of the buttons is filled, because the data has been entered and the official issue has been requested. Nevertheless, the buttons are still functioning as the data can be edited and the request can be sent again in case an expert declined it or building data was changed.

Types of Questions

Depending on the required input, different question types are used for the data acquisition. The general layout as well as the most important variations are given in Section 3.8, some additional ones will be described in the following.

Image Upload
In some cases, users need to upload a picture which will be analyzed to deduce technical information. For example, the meter cabinet should be photographed, since queries about its condition would be too specific and difficult to answer for lays. Figure 28 shows how the kind of picture required is demonstrated at the top of the screen, while a rectangle below acts as a placeholder for the user's image. Two buttons at the bottom allow to either select an image from the gallery or take a new photo now, each of them opening the corresponding tool on the device. Once the user has uploaded an image, it appears in the designated place, such that users can compare it to the example before they move on to the next question.

Enumeration
In order to estimate the condition of the building and its components, users should indicate any renovations conducted so far in addition to the construction year. While this could be handled with a series of multiple questions asking which renovations have been conducted and when, it was decided to be queried in one screen in this work. This has the advantage of collecting all pieces of information in this context in one spot, where the user can easily retrieve it, get an overview and correct details if necessary. Figure 29 shows the design of the screen, which initially shows the default answer that there have not been any renovations. By tapping on the plus button, users can add an item to the list, revealing three drop-down menus for the year, area and type of renovation. The area refers to the part of the building that has been renovated, i.e., the roof or windows, while the type specifies what has been done. These are the three main pieces of data needed for every renovation and they can be supplemented by

Figure 28: This screen is used whenever the user needs to upload an image. At the top, an example is shown in order to demonstrate what the picture should look like, and below there is a placeholder field where the image will be inserted. This can be done by either selecting a picture from the gallery or taking a photo now.

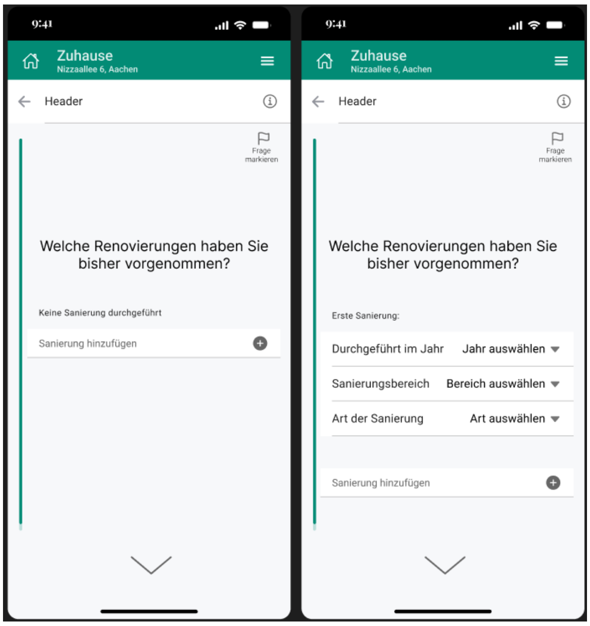


Figure 29: With this screen, users can indicate an arbitrary number of renovations that have been conducted on the building. For each of them, the renovation year, the area of renovation and potentially further specifics must be given.

additional data that is specific for individual renovations. Whenever such an addition is necessary, a corresponding drop-down menu appears beneath the other ones. Note that a drop-down menu is not always the optimal choice as input type for these facts. Even among the three initial menus, the available options are not clearly predictable for the user, so the selection would usually be presented by radio buttons. However, this would make the collection of data for one renovation lengthy. Users may find it harder to get an overview of their input or differentiate between multiple renovations in the list. The drop-down menu is an efficient way to display the data in one line and thus summarize a renovation compactly. Upon tapping on the selection caret, users can still scroll through the options and select the most suitable one.

Slider for quality levels

As described in Section 2.2, the precise computation of the building's market value requires an assessment of the quality of the nine main areas of the building, including for example the roof and the outside floors. Since intermediate values between two levels should be allowed, a slider is the natural choice for this input. The difficulty is that each of the five quality levels must be explained in detail, so the user is able to classify their house correctly. Ideally, these explanations should be displayed simultaneously to allow a direct comparison. While this is not possible for all explanations at once due to their length, it can be done for at least two adjacent levels. Figure 30 shows how the question is designed. The quality descriptions are given on a band that can be scrolled through sideways and the slider below contracts this band to screen width. Both elements are synchronized, such that the slider marks the position of the band that is currently displayed. Users should intuitively understand this connection while they scroll through the band in order to read the descriptions and then be able to move the slider to a suitable level.

Creation of a floor plan

The detailed computation of energy efficiency and heat demand requires information about individual components and rooms of the building and in what relative position they are to each other. Indicating this in an abstract way would be sufficient, but challenging for the user as they would need to keep an overview about all components and which data set refers to which object or room in the real world. To facilitate this, the user is asked to provide a floor plan. Therein, they can easily recognize each object and answer its specific questions, while locations and interdependencies like ventilation zones are automatically deduced by the program.

Since the creation of a floor plan is a rather elaborate task, existing tools on the internet were consulted to develop a suitable design. They usually provide several functionalities beyond the need of the SmartRenovation App: Some of them can be used to create any kind of diagram and are not directly optimized for floor plans [50] [51]. Others are

[50]https://www.edrawsoft.com/de/edraw-max/

[51]https://www.lucidchart.com/pages/de

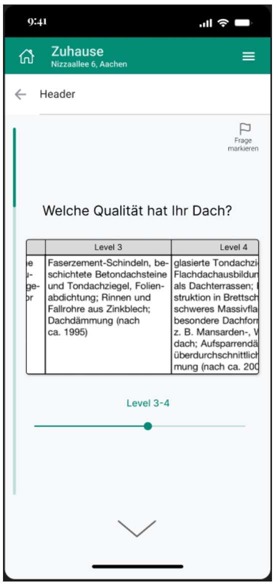
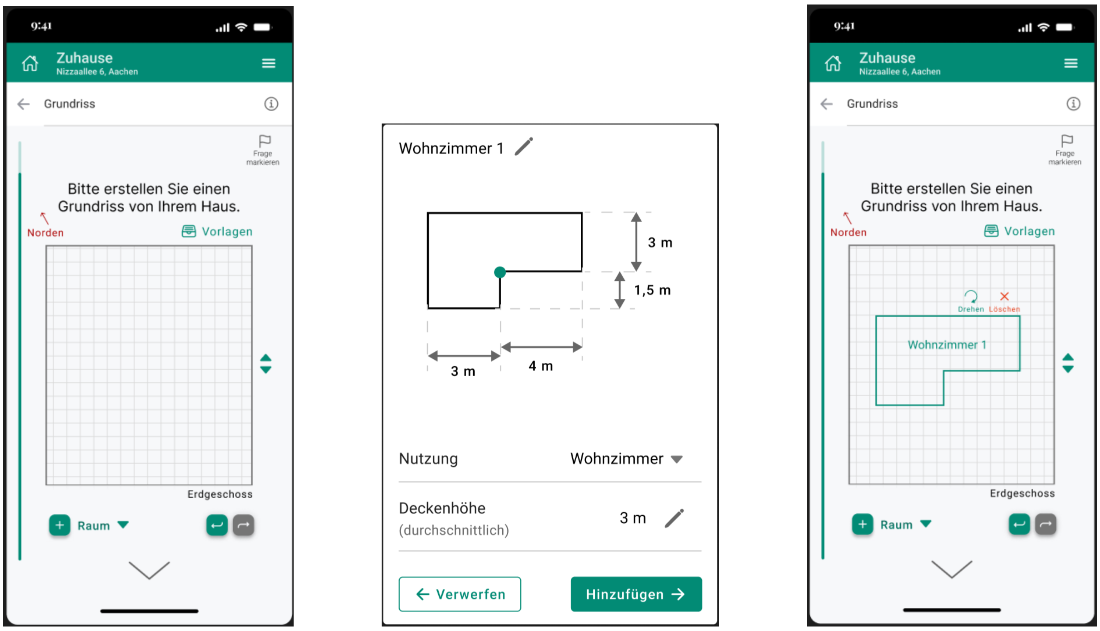


Figure 30: This slider is used to indicate the quality level of the building's roof. The descriptions of the five levels can be scrolled through by moving the green knob below or swiping on the table itself.

conceived to create a complete interior design [52] [53] [54] and allow users to add furniture, decorate their rooms and specify additional properties like style and color. Since these things are not relevant to the SmartRenovation app, a large part of the interface components can be omitted. Several tools are especially advertised with the possibility of rendering a 3D visualization of the room or building. This functionality allows users to look at their design from different angles and assess whether they are satisfied with the resulting atmosphere. In the SmartRenovation App, the floor plan should simply provide an intuitively understandable overview of the rooms in the building, such that the user can easily recognize where they need to answer further questions. For this purpose, a three dimensional view would not bring any benefit but only complicate the plan creation as well as the navigation between floors. Therefore, this feature was also omitted in the SmartRenovation App.
Figure 31a shows the initial, empty floor plan, where the user can insert various components by selecting them from the drop-down menu at the bottom. Per default, a room is selected, since rooms are the main components of a floor plan and should be added at first. The plus button opens an overlay where the extents of the room or component can be specified as shown in Figure 31b. The walls and corners of the room can be moved arbitrarily in the graphic at the top, where the dimensions are immediately adapted. Alternatively, the dimensions can be directly entered by tapping on them, which in turn changes the graphic accordingly. In a drop-down menu, the usage of the

[52] https://www.roomarranger.com/
[53] http://www.sweethome3d.com/
[54] https://www.roomsketcher.de/



(a) Initially, the floor plan is empty, but its length, width and levels are given in accordance with the previous user input. The button at the bottom left allows to add rooms and other components while the buttons on the right can be used to undo the previous action and redo it.

(b) This pop-up allows the specification of a room with its dimensions and usage. The room's form is displayed at the top and can be adapted by dragging walls and corners around or entering the measurements directly in the labeling. Other components of the building like windows and doors are specified in a similar pop-up, where the characteristics to be specified at the bottom differ slightly.

(c) After specifying a room, it appears in the middle of the current floor plan and can be moved to its respective place. The green lines mark it as selected and turn black once the user tabs somewhere else. Two buttons at the upper right corner allow to rotate the room or delete it from the plan.

Figure 31: These figures illustrate the process of creating a floor plan of the house. Users can either choose a template plan out of a predefined set and adapt it to their needs or create their own plan by adding components one by one.

room should be selected, which determines the default room title shown in the upper right corner. This is the title that will be later displayed in the middle of the room in the floor plan but it can be adapted arbitrarily. Additionally, the ceiling height should be indicated in a text field. To accelerate the process, this field is automatically filled with a default value or one that was previously entered for another room. Once the user is done with the specifications, they can add the room to the floor plan by means of the respective button, which is filled in the application's typical green to guide the user's attention. The overlay closes and reveals the floor plan again, where the just created room can be moved and rotated to its designated place.

By adding one room after another and subsequently the other components like doors, windows and staircases, the whole floor plan is built. Users can navigate to other levels of the building and construct them in the same way by using the arrows on the right. Note that the activation area of these arrows is larger than the icons to facilitate the selection. Switching between the levels by scrolling is not supported here, since this could easily lead to conflicts with scrolling between questions of the underlying questionnaire. The label at the bottom right corner of the floor plan indicates the currently displayed level.
One important feature that was adopted from existing tools is the possibility to select a template from a predefined set. Many buildings have a similar architecture, such that users only need to change some details and can finish the plan in substantially less time. A respective button was added in the upper right corner of the screen, it opens an overlay to select from several complete floor plans. Many other tools also allow positioning a predefined component from a sidebar onto the plan, but this requires a lot of space which is not available in the mobile application.
Furthermore, a grid mesh was added in the background of the plan, such that users can estimate the dimensions more easily. Changing them should also be possible directly in the plan by double tapping on walls or corners and moving them around.

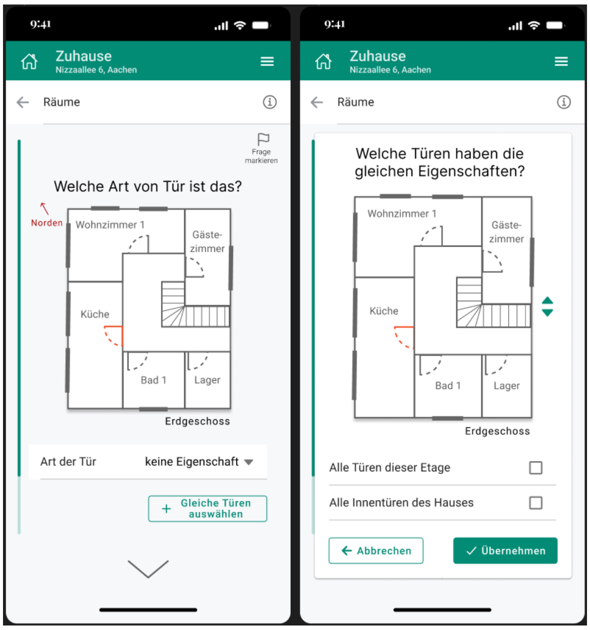


Figure 32: For component-specific questions, the respective building part is marked in the floor plan, such that users can easily recognize which object the question refers to. The button at the bottom allows to select other components in the floor plan, that have the same characteristic, since components are often used multiple times in a building. This functionality can significantly decrease the number of questions that need to be answered. These questions can only be dealt with after the creation of a floor plan has been completed.

A difficulty here is the specification of curved or diagonal walls, while also allowing to add corners to a room by dragging an existing one to the inside. No intuitive solution for this was found in existing tools, as the effect of moving a corner seemed often unpredictable. However, since most building walls are straight, this feature is not expected to be required in many cases and is omitted in the current version. Note in this context that the exact definition of walls is not significantly relevant for the computations and a curved wall can be abstracted from for now. Nevertheless, future versions should include this feature in order to be specific for any building.

Room and component specific questions
After the floor plan has been specified, detailed questions specific to individual rooms and other building components can be asked. This is done by marking the related component in the floor plan below the question as shown on the left in Figure 32. Via a button at the bottom, an overlay can be opened to select all components in the building that have the same characteristic as the one currently worked on. In the given example, the question refers to a door, so the overlay allows to select other doors with the same characteristic. This way, the same question does not need to be asked for every door, since many of them are dealt with at once. Checkboxes in the overlay allow to conveniently select all doors on the current level or in the whole house, further accelerating the process.

Photovoltaic parameters

Figure 33: These excerpts of the module placement on the photovoltaic detail page show how previously placed modules can be rotated and are marked red when they violate the distance constraints to obstacles on the roof or to the roof's edge. Such violations should be automatically resolved by slight displacements, if possible.

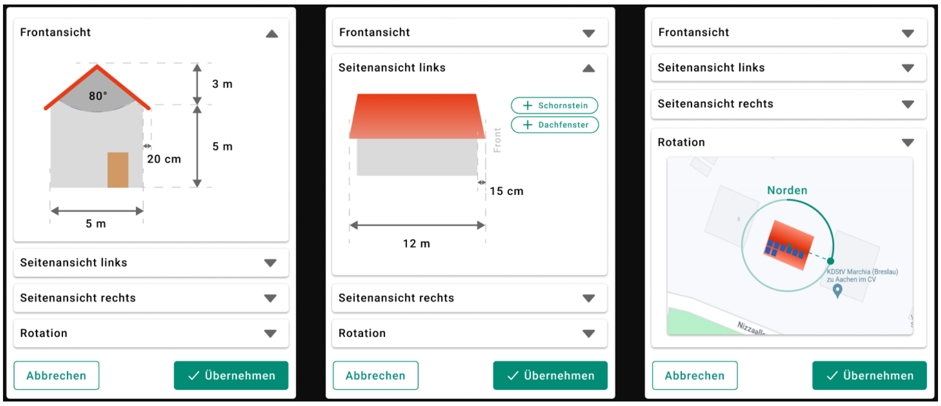


Figure 34: This overlay with different views allows to edit the precise measurements of the roof on the detail page of a photovoltaic project. The measurements can be entered directly in the labels as in a text field or adapted dynamically by moving the respective border lines. Note that these are simplified graphics that do not apply to all houses. In a future version of the SmartRenovation app, the measurements should instead be specified in real images of the house.

Contacting an Expert

Upon tapping on the button to contact an expert on one of the project pages, the screen shown in Figure 35 is displayed. Depending on the source project, it lists craftsmen specialized in the area that is needed for the respective project. Thereby each expert is given with an image, their name, profession, contact info and a rating from previous clients. The latter can help the user to select an expert to contact and the contact info enables them to conveniently do this immediately: A web link leads directly to the website of the expert if they have one, the mail address opens the user's mail program and the telephone number initiates a call. In case of the mail, a default letter is automatically set up with the data sheet of the project attached to it. This way, the user does not need to put any further work into the communication and should be more inclined to carry out the planned project. Note that all this information requires an extensive database of craftsmen, which is currently not available. So far, only information from Google can be used.
At the bottom of the screen, an additional button allows to print the house and project data to a PDF file, in case users are not satisfied with any of the listed experts and prefer to contact someone externally.

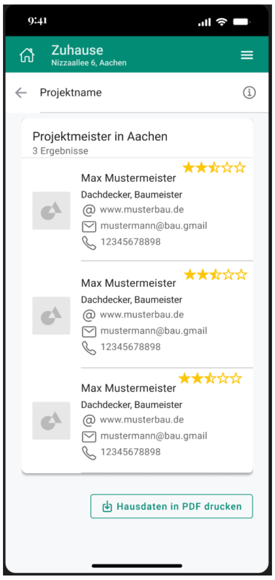


Figure 35: From this screen users can select an expert for the project specified in the header. The list shows craftsmen in the area of the building that offer services needed for the respective project. Users can choose between contacting the experts via their website, via mail or via telephone and upon tapping on it the respective tool is opened on the user's device.

C. Appendix C

1. Wie alt sind Sie?
2. Welches Geschlecht haben Sie?
3. Wie lange besitzen Sie Ihr Haus schon?
4. Haben Sie Ihr Haus schon energetisch saniert?
5. Ich war bei der Bauplanung meines Hauses stark beteiligt.
6. Die energetische Effizienz des Hauses war während der Planung ein sehr entscheidender Faktor.
7. Ich habe noch nie darüber nachgedacht, mein Haus energetisch zu sanieren.
8. Ich habe mich sehr gründlich über Möglichkeiten informiert, wie ich mein Haus energetisch sanieren kann.
9. Ich möchte eine Photovoltaikanlage auf meinem Haus installieren.
10. Haben Sie sich schon ein Mal im Detail über die Kosten und Vorteile einer Photovoltaik Anlage in Ihrem persönlichen Fall informiert?

List 1: These questions and statements are included in the preliminary questionnaire of the evaluation study. Thereby, participants were asked to rate the statements according to their agreement on a Likert scale from one to five. The questionnaire aims to determine the participants' background and experience with similar tools related to the renovation of residential buildings.

1. Ich kann mir gut vorstellen, die App weiter zu nutzen.
2. Ich empfinde die App als unnötig komplex.
3. Ich empfinde die App als einfach zu nutzen.
4. Ich denke, dass ich technischen Support brauchen würde, um die App zu nutzen.
5. Ich finde, dass die verschiedenen Funktionen der App gut integriert sind.
6. Ich finde, dass es in der App zu viele Inkonsistenzen gibt.
7. Ich kann mir vorstellen, dass die meisten Leute die App schnell zu beherrschen lernen.
8. Ich empfinde die Bedienung der App als sehr umständlich.
9. Ich war während der Nutzung der App oft unsicher, was ich tun soll.
10. Ich musste eine Menge Dinge lernen, bevor ich mit der App arbeiten konnte.
11. Ich habe die Fragen in der App leicht verstanden.
12. Ich konnte die Fragen in der App leicht beantworten.
13. Fachbegriffe in der App wurden gut erklärt.
14. Ich würde die App einem Freund oder Nachbarn empfehlen.
15. Ich fühle mich jetzt besser über die Möglichkeiten, wie ich mein Haus renovieren kann, informiert.
16. Ich bin jetzt motiviert, mein Haus zu sanieren.
17. Ich möchte den Sanierungsempfehlungen der App folgen.
18. Ich möchte eine Photovoltaikanlage auf meinem Haus installieren.
19. Ich vertraue den Ergebnissen der App.
20. Im Vergleich zu ähnlichen Tools zur Bewertung von Häusers oder der Abschätzung von Renovierungskosten finde ich die getestete App...

List 2: Participants of the study were asked to rate these statements according to their agreement on a Likert scale from one to five. The first ten sentences are based on the statements in Brooke's System Usability Scale [4], the rest was added for a specified assessment of the application's usability. Furthermore, the responses should indicate whether the app successfully informed and motivated users to conduct an energetic refurbishment of their house. The last statement consists of multiple rows, allowing participants to indicate their perception of various attributes in the app.

	Wie alt sind Sie?	Welches Geschlecht haben Sie?	Wie lange besitzen Sie Ihr Haus schon?	Haben Sie Ihr Haus schon energetisch saniert?	Ich war bei der Bauplanung meines Hauses stark beteiligt.
Participant 1	über 60 Jahre	weiblich	mehr als 25 Jahre	Nein	4
Participant 2	40 bis 60 Jahre	männlich	6 bis 12 Jahre	Nein	5
Participant 3	25 bis 39 Jahre	weiblich	6 bis 12 Jahre	Nein	5
Participant 4	über 60 Jahre	männlich	mehr als 25 Jahre	Nein	5

	Die energetische Effizienz des Hauses war während der Planung ein sehr entscheidender Faktor.	Ich habe noch nie darüber nachgedacht, mein Haus energetisch zu sanieren.	Ich habe mich sehr gründlich über Möglichkeiten informiert, wie ich mein Haus energetisch sanieren kann.	Ich möchte eine Photovoltaikanlage auf meinem Haus installieren.	Haben Sie sich schon ein Mal im Detail über die Kosten und Vorteile einer Photovoltaik Anlage in Ihrem persönlichen Fall informiert?
Participant 1	4	1	2	3	Ja, ich habe selbstständig oder mit einem Programm die Kosten und/oder Vorteile in meinem persönlichen Fall berechnet.
Participant 2	3	5	2	5	Ja, ich habe mich von einem Experten für meinen individuellen Fall beraten lassen.
Participant 3	4	1	2	3	Ja, ich habe mich von einem Experten für meinen individuellen Fall beraten lassen.
Participant 4	3	4	3	4	Nein, für meinen individuellen Fall habe ich mich nicht informiert.

Figure 36: These are the participants' responses to the preliminary questionnaire of the user study. The numbers of one to five thereby connote the participants' agreement to the given statement on a Likert scale.

	Ich kann mir gut vorstellen, die App weiter zu nutzen.	Ich empfinde die App als unnötig komplex.	Ich empfinde die App als einfach zu nutzen.	Ich denke, dass ich technischen Support brauchen würde, um die App zu nutzen.	Ich finde, dass die verschiedenen Funktionen der App gut integriert sind.
Participant 1	5	1	4	3	3
Participant 2	4	2	4	2	5
Participant 3	3	1	5	1	5
Participant 4	4	1	4	1	5

	Ich finde, dass es in der App zu viele Inkonsistenzen gibt.	Ich kann mir vorstellen, dass die meisten Leute die App schnell zu beherrschen lernen.	Ich empfinde die Bedienung der App als sehr umständlich.	Ich war während der Nutzung der App oft unsicher, was ich tun soll.	Ich musste eine Menge Dinge lernen, bevor ich mit der App arbeiten konnte.
Participant 1	2	5	1	3	1
Participant 2	4	2	2	3	1
Participant 3	1	5	1	2	1
Participant 4	1	5	1	2	1

Figure 37: This table shows the participants' agreement to the statements derived from Brooke's System Usability Scale by means of Likert scores from one to five [4].

	Ich habe die Fragen in der App leicht verstanden.	Ich konnte die Fragen in der App leicht beantworten.	Fachbegriffe in der App wurden gut erklärt.	Ich würde die App einem Freund oder Nachbarn empfehlen.	Ich fühle mich jetzt besser über die Möglichkeiten, wie ich mein Haus renovieren kann, informiert.
Participant 1	5	3	4	5	3
Participant 2	2	2	4	3	3
Participant 3	5	2	4	5	4
Participant 4	5	4	5	5	3

	Ich bin jetzt motiviert, mein Haus zu sanieren.	Ich möchte den Sanierungsempfehlungen der App folgen.	Ich möchte eine Photovoltaikanlage auf meinem Haus installieren.	Ich vertraue den Ergebnissen der App.
Participant 1	3	3	4	3
Participant 2	1	2	5	3
Participant 3	3	2	3	3
Participant 4	2	1	4	4

Figure 38: This table depicts the study participants' agreement to the additional statements in the subsequent questionnaire by means of Likert scores from one to five.

	Im Vergleich zu ähnlichen Tools zur Bewertung von Häusern oder der Abschätzung von Renovierungskosten finde ich die getestete App ... [übersichtlicher]	Im Vergleich zu ähnlichen Tools zur Bewertung von Häusern oder der Abschätzung von Renovierungskosten finde ich die getestete App ... [informativer]	Im Vergleich zu ähnlichen Tools zur Bewertung von Häusern oder der Abschätzung von Renovierungskosten finde ich die getestete App ... [komplizierter]	Im Vergleich zu ähnlichen Tools zur Bewertung von Häusern oder der Abschätzung von Renovierungskosten finde ich die getestete App ... [zielgerichteter]
Participant 1	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.
Participant 2	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.
Participant 3	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.
Participant 4	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.	Ich kenne keine ähnlichen Tools.

Figure 39: Here, participants were asked to compare the SmartRenovation App with similar tools, but none of them knew any.

	Was hat Ihnen an der App besonders gut gefallen?	Was könnte besser sein?	Möchten Sie sonst noch etwas sagen?
Participant 1	Übersichtlichkeit, Strukturierung, Farbgestaltung.	Die Frage nach der Renouvierung war für mich nicht eindeutig, ob sie sich nur auf Energieeffizienz bezog oder auch auf Werterhaltung des Hauses. Die Möglichkeit der Eingabe mehrfacher Instanthaltung wurde erst durch Probieren klar.	Ich denke, dass die Erstellung einer solchen App sinnbringend ist. Wünsche viel Erfolg!
Participant 2	Navigation, Layout allgemein, (potentieller) Umfang	Zurück-Button, Schriftgröße, Datenschutzerklärung, Account-System	
Participant 3	Die grafische Veranschaulichung, inkl. Diagramme, die übersichtliche Bedienbarkeit	Ausführlichere/konkretere Hinweise zu den empfohlenen Sanierungen	
Participant 4	übersichtlich und leicht auszufüllen	auf Teile, die noch fehlen, sollte hingewiesen werden	danke

Figure 40: This table shows the responses given in the free text fields at the end of the user study.

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