Frank Elberzhager, Steffen Hupp, Svenja Polst, Phil Stüpfert,
Arne Surmann

19 A Climate-Neutral Smart City District Supported by Digital Solutions

Summary: The digital transformation is able to support a climate-neutral smart city district in various ways. We have focused on the users living in such a smart city district and have developed concepts and concrete solutions. In this chapter, we give an idea of the technical background and provide several examples from different domains, such as mobility, energy, and smart home. We discuss the challenges we encountered and how we solved them.

19.1 Introduction

The digital transformation and climate change are two of the greatest current megatrends. In the EnStadt:Pfaff research project, our main goal is to develop a climate-neutral smart city district. One question is how digitalization can support climate-friendly behavior in a smart city. To help answer this question, we have developed concepts and solutions to show how this can be implemented.

One basis for digital solutions are so-called digital ecosystems. From the technical point of view, such a digital ecosystem consists of a platform and various digital services. Different stakeholders participate in such an ecosystem by offering or consuming services. These services should support, for example, citizens in their climate-friendly behavior, for instance, by sharing information, but also by offering concrete apps that give hints on how to save energy. One important aspect in our project is our focus on the user perspective, i.e., we concentrate on and address real needs.

The question remains how the digital transformation can support climate neutrality in such a smart city district. In this chapter, we want to share some examples showing what solutions we have developed, but also what challenges we have faced.

Frank Elberzhager, **Steffen Hupp**, **Svenja Polst**, **Phil Stüpfert**, **Arne Surmann**, Fraunhofer Institute for Experimental Software Engineering IESE, Germany

https://doi.org/10.1515/9783110777567-019

19.2 Starting Situation and Main Challenges

In an early phase of the research project, we initially thought about what principles we wanted to follow when developing digital solutions. Our main driver was to be user-centric and future-oriented. In detail, we formulated the following guiding principles:

– The Pfaff district offers an excellently developed digital infrastructure for businesses, users, and residents in the district and is becoming an important building block of the "Herzlich-Digitale Stadt Kaiserslautern" initiative.
– The digital district platform unobtrusively supports quality of life and climate protection in the neighborhood. The platform offers services for many areas of daily life, such as energy, mobility, home, and community, which are interconnected.
– People's needs are at the heart of the digital platform, and all services and development activities are geared towards them. Citizens and users are actively involved in the development.
– The digital platform promotes the development of new services for the district and enables the linking of data from different services and external infrastructures. Through their interaction, innovative approaches to solutions for climate protection and a high quality of life in the district are created.
– The digital platform is open to participation by citizens and companies. It provides the technical and organizational framework for planning and developing, establishing, and deploying low-barrier digital services during development and after completion of the district.
– The digital platform and its services are committed to privacy protection. Privacy measures ensure compliance with legal requirements and build trust with people. Open access to data of general interest makes the district transparent for residents and users as well as other stakeholders.

However, one major challenge for us was the time-consuming construction work, which means that we have only very limited access to users of the future district. Therefore, we needed alternative ways to derive requirements and concepts for our digital solutions, as we could not ask users directly.

19.3 Technical Background

In this chapter, we provide some more details about our technical solution, which is the basis for most of the developed concepts, digital prototypes, and solutions.

The digital district platform supports the creation of applications in the context of the digitalization of the Pfaff smart city district. On the one hand, concrete applications are being developed in the project; on the other hand, it should also be possible for external partners to make digital services available in the long term. The platform provides basic services that can be used to easily create new services. The focus is strongly on applications with direct user interaction, which are provided as mobile applications or web applications. Examples of basic services are user management, application and application version management, collection of all user data across applications, deletion or anonymization of user data across applications, chat services, or image services. These basic services can be used by applications and thus make it possible to focus on the actual added value of the service. The platform is operated in a cloud-based environment that scales automatically and can therefore serve a fluctuating number of users and load. End users do not interact directly with the platform, but via the services provided on the platform.

An overview of the conceptual architecture of the platform is shown in Figure 19.1. A fundamental distinction is made between applications on the platform and the platform itself. Users mainly interact with the applications; only for cross-sectional aspects such as registration or data information is there direct interaction with the platform. The applications themselves are divided into a frontend and a backend part. The task of the frontend is to enable direct interaction with an individual user. These frontends are often apps installed on a device or web applications executed in a browser. The backend part of the applications, on the other hand, has a different requirement. It ensures that there is a regulated exchange of data between the individual frontends of the application. In the example of a chat application, the frontends of the users would send the messages to the backend, which in turn would make these messages available to exactly those frontends whose users have access to them. In addition, the backend parts of the applications also allow for inter-application exchanges. For example, an application that organizes rides could be directly integrated as a bot into a chat application.

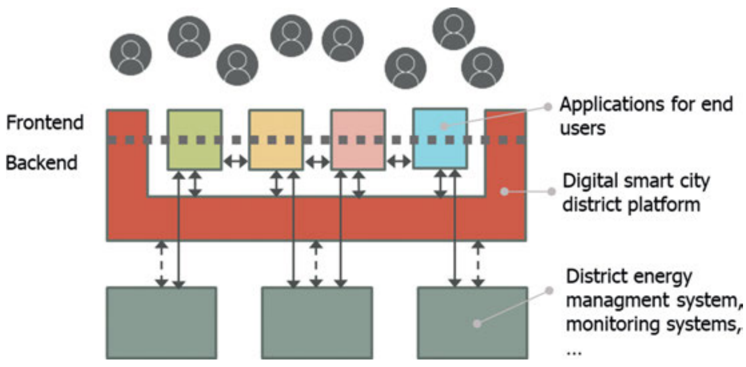

Figure 19.1: Overview of the platform concepts.

Analogous to the division into frontend and backend for the applications, such a division also exists for the platform. The platform has only few frontends since direct user interaction is rather rare, for example when registering and logging in to the platform. The main task of the platform is to simplify the backend parts of the applications. This is where the services of the platform described above come into play, which relieve application developers of a large part of the complexity in developing an application. Data is handled appropriately, and qualities such as performance, security, or the GDPR requirements are explicitly considered in our solution architecture.

As already mentioned above, due to the fact that we currently have no real users in the Pfaff district, it does not make sense to implement such a platform in the district itself. However, we needed an environment where we would be able to test new ideas, prototypes, and digital solutions. Such digital solutions often also run on a platform. However, the aforementioned platform is being developed to run and offer services, but not to test ideas and prototypes. Therefore, we decided to develop a so-called mock platform. The basic idea is to have a technical framework that offers, in particular, ways of testing new services and ideas, while neglecting qualities such as performance or privacy.

The mock platform consists of four components. The core is an event broker. All participants (services) can easily communicate with each other via this event broker. The MQTT protocol is used, which is supported by all common programming languages and IoT devices.

The second component of the mock platform are the services, which provide basic functions that are always needed during prototype development. These include, for example, cloud storage, which can be used to exchange large volumes of data, and a user service, which can be used to create and manage users.

The third component is the introduction of so-called “shared topics”. These aim to simplify communication between existing and newly added applications by standardizing communication. The selected communication rules make it possible for existing applications to receive and process messages from newly added applications without having to adapt existing implementations.

The last component is a feedback component that can be used to analyze the communication taking place over the mock platform. This component provides detailed insights into the communication of a prototype, such as average message size, sending rate, number of recipients, etc. The resulting information can be used for communication optimizations of future applications.

An overview of the used technology and concepts can be found in Figure 19.2.

19.4 Digital Application Examples from the Smart City District

In this chapter, we will show some of the concrete prototypical digital examples that we developed.

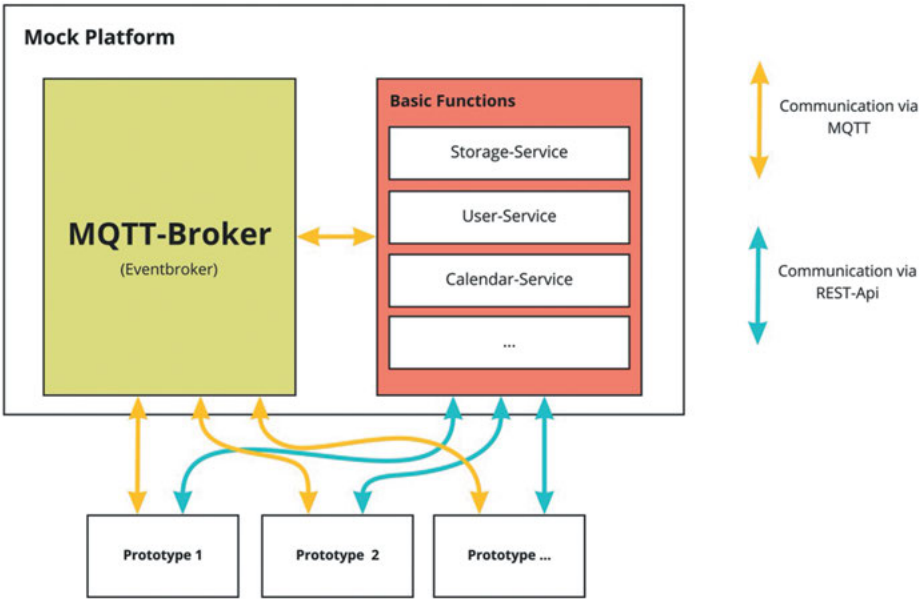

Figure 19.2: Mock platform technology.

19.4.1 MiniLautern

Imagine a district where kids can safely play near the road, where cycling is fun and safe, where space for humans is more important than space for cars. Imagine a quiet district without traffic noise but with good air quality. To achieve this kind of district, more people need to use ecofriendly ways of traveling instead of using their own car.

Behavior change all starts with realizing the good of the change, for yourself and your loved ones. We want to demonstrate the positive effects of ecofriendly mobility to people, but without giving them the feeling of being lectured or reprimanded for using their car.

Therefore, we designed the game “MiniLautern” (short for: small Kaiserslautern). The web-based game is a single-player game. At the beginning of the game, the fictional person Ellen Mask introduces the player to the task: choose mobility measures for the Pfaff district that make the citizens happy, improve the quality of life in the Pfaff district, and reduce the negative impact on the environment.

In each round, players get to know fictional citizens in the district. They can read about the citizens’ needs and regular travel destinations. There are diverse fictional characters so that the players can empathize with at least one of them. Thereafter, they select a mobility measure and receive feedback regarding the impact on environment, quality of life, and happiness.

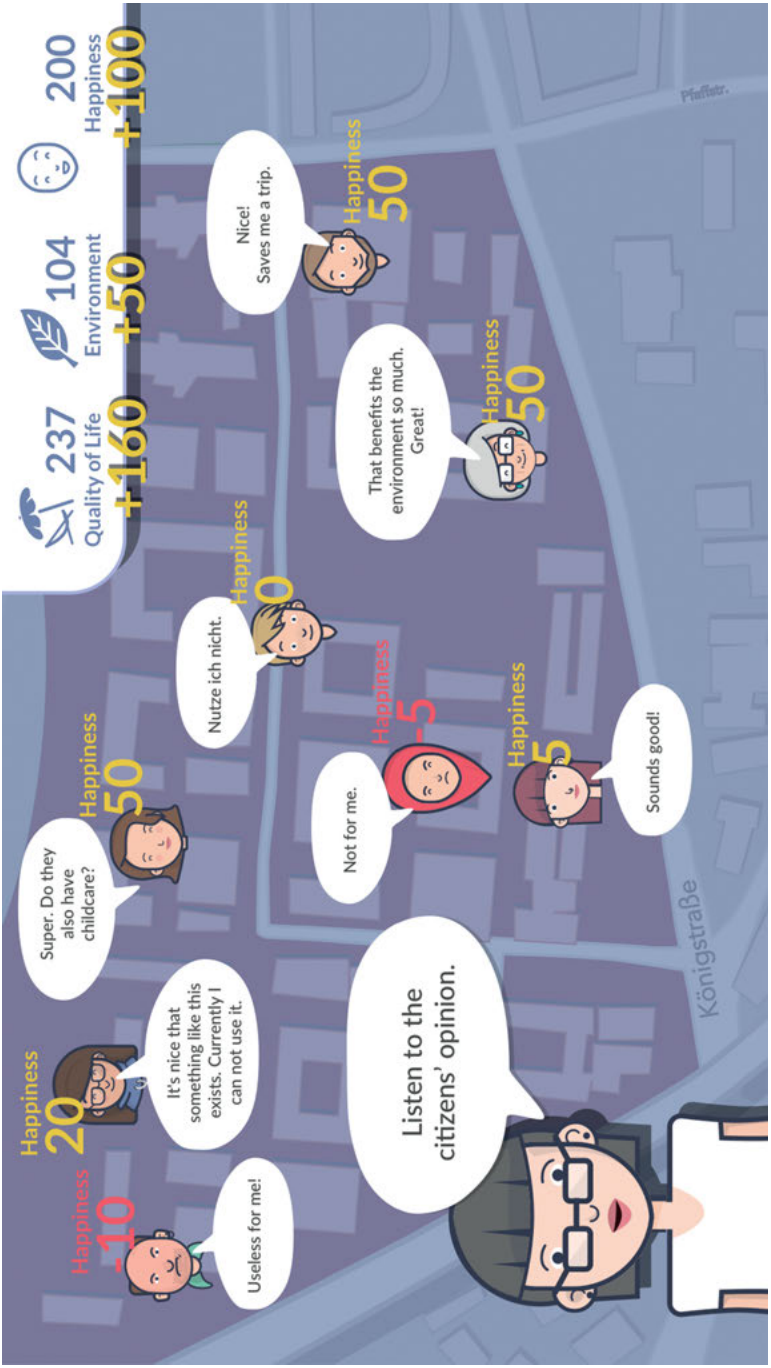

Figure 19.3: MiniLautern user interface.

In short, the game introduces mobility measures that are indeed foreseen for the district or that could be part of the district but are currently not planned. The game stresses the positive effects of the mobility measures and thereby increases the citizens' acceptance of these mobility measures.

The game can be played online.[1] It is available in German only. Further background can be found in a video.[2] Some impressions are provided by Figure 19.3 and 19.4.

19.4.2 Fish 'n Tipps App

The second example is the Fish 'n Tipps app. This solution prototype is being developed in the area of energy and community. The core idea is that a personal avatar, represented here as a fish, gives hints and tips on how to behave in a more climate-friendly way. The tips come from two sources: Elberzhager, Mennig, Polst et al. (2021) from other residents of the district and other users of the app (i.e., the community idea); EnStadt:Pfaff (2019) from the digital ecosystem itself, where our app "listens" to other apps and responds with appropriate tips. This means that users interact with the app, and several kinds of data is handled within the app. One example is that the app knows that the weather is good, there are still bikes available at a nearby rental station, and the user's next appointment is only two kilometers away; then our Fish 'n Tips app can suggest that the user can take a bike instead of a car.

The user can then decide whether they want to do that and can follow this tip. There are also gamification elements in this app, from the look and feel to "little competitions" where users can collect points. Our goal here is to provide a digital assistant that gives advice on how to save energy and offers networking between people. A screenshot can be found in Figure 19.5.

19.4.3 PfaffFunk

To provide information to interested citizens and other involved parties and to support the dialog between them and the project partners, a communication app named "PfaffFunk" (German for Pfaff radio) was developed and is available on iOS and Android. It is a variant of the "DorfFunk" (German for village radio) app developed in another research project.

PfaffFunk is a small social network in which users can exchange public posts on which others can comment. News and event announcements from the project website are also being pushed as dedicated post types into dedicated categories in PfaffFunk,

1 Available at: https://www.minilautern.de/ (Accessed: 30 April 2022).
2 Available at: https://www.youtube.com/watch?v=7Z7V9vlZBbA (Accessed: 30 April 2022).

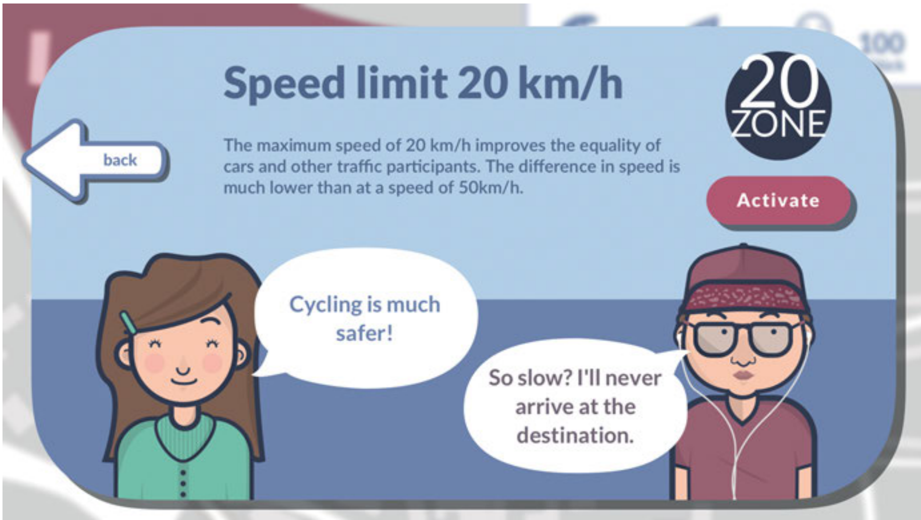

Figure 19.4: MiniLautern view on a mobility concept.

Figure 19.5: Fish ’n Tipps App.

and users can comment and like them. Users can show an interest in posted events as an indication that they want to participate. There is also a possibility to define groups, e.g., to discuss certain aspects like environmental protection. Users can also begin private chats with other users who publicly posted or commented on something. Posts can contain several images as well as post-type-specific metadata, like news category or event location and date.

Another feature of the app is an overview of other services available to the app's target group. In PfaffFunk, these services encompass the other solutions developed within the project as well as information sources, like MiniLautern or the YouTube Channel of the "Quartierswerkstatt". A different feature being developed for Pfaff-Funk is a feedback mechanism to allow providing feedback regarding the app's functionalities from within the app, e.g., after using a specific functionality for the first time. This is done to improve existing features and develop new features based on direct user feedback. Some impressions are given in Figure 19.6.

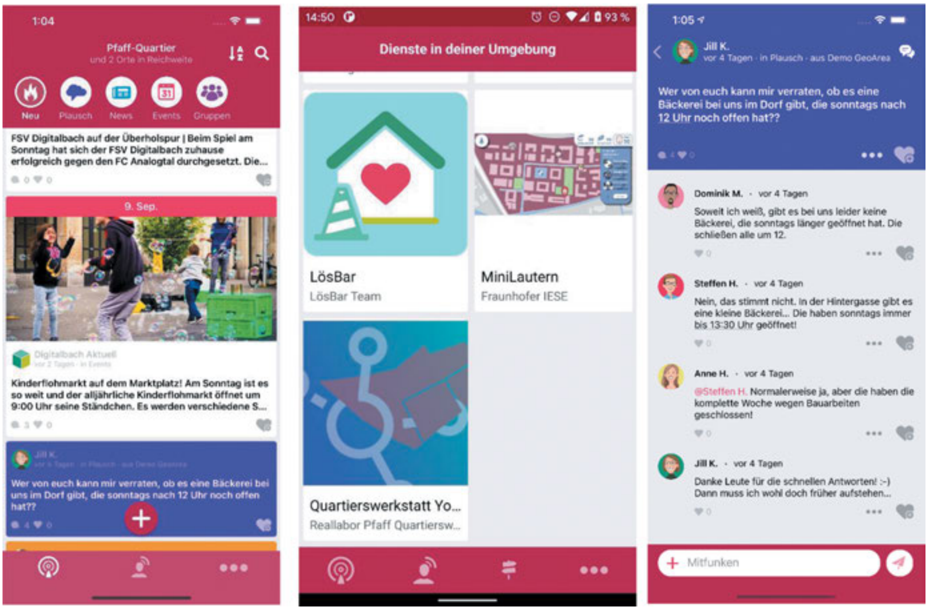

Figure 19.6: PfaffFunk app.

19.4.4 Conclusion

We have developed several concepts, prototypes, and initial solutions and showed how the digital transformation can support a climate-neutral smart city district. Of course, these can only be considered a starting point, especially due to our main challenge of not being present in the district itself because construction work is so slow. However, we developed and implemented solutions and got initial evaluation results via direct feedback from users or via questionnaires. More information can be found on our YouTube channel[3] or in Elberzhager/ Mennig/Polst et al. (2021).

19.5 Smart Home

After providing a general overview of example smart city applications, we will show in this chapter how connecting multiple individual applications within a city district platform can create synergies that provide additional value on top of the individual benefits. As an example, we chose the Pfaff smart home system, as it provides a prominent entry point into the digital Pfaff universe. A classical smart home system consists of a smart home hub, which houses a computing unit that hosts a logic to connect various sensors and actuators within a defined area.

The most prominent use case of smart home systems is their function as a multimedia interface with a strong focus on lighting installations in residential houses or apartments. Further popular applications are security systems, including camera installations and break-in alarm sensors, or ambient assisted living applications, with sensors detecting falls or emergency buttons to request help. A less popular application in the past, which is, however, making rapid gains with the increase of PV installations and wallboxes for charging electric vehicles is the topic of energy management and energy saving. Within the Pfaff project, we focused on the energy-saving aspect and asked how a smart home system can help decrease energy consumption without violating any user comfort settings. In fact, within the developed system, an increase in comfort is possible by automating formerly manual processes. Further requirements were derived from the EnStadt:Pfaff mission statement (EnStadt:Pfaff 2019), extended by a list of points we consider important for an interconnected energy-saving smart home. The requirements are listed in Table 19.1.

Table 19.1: Requirements for the EnStadt:Pfaff Smart Home System retrieved from Surmann, Bär, Heupts et al. (2019).

Primary energy targets			
1.	Save energy	2.	If energy saving is not possible, optimize the usage in the most efficient way
3.	Use local and renewable energy	4.	If no local energy is available, use external renewable energy

3 Available at: https://www.youtube.com/channel/UCK8LjvcvaCHBF-voo0qcqqA (Accessed: 30 April 2022).

Table 19.1 (continued)

Additional functional targets			
5.	Generate value for all people of various ages and with various lifestyles	6.	Guarantee comfort or increase it
7.	Provide a high-quality indoor climate	8.	Guarantee data privacy
9.	Measure and visualize energy usage	10.	Provide energy consumption for performance evaluation
11.	Create a user interface to the ICT environment and follow a user-centered design.	12.	Provide recommendations for changes in user behavior towards a sustainable lifestyle
13.	Use a resilient infrastructure	14.	Provide sensor data for other ICT apps
15.	Use open systems that are adaptable and can include various devices	16.	Be scalable for the whole neighborhood

To showcase the Pfaff smart home system, we had planned a demonstrator installation in the Pfaff neighborhood, but due to delays in the building construction and renovation process, we replaced the chosen apartment with a digital twin, including an electrical device simulation, using the Fraunhofer tool synPRO (Fraunhofer ISE 2022) and a smart home visualization (see Figure 19.7).

In addition, we installed some prominent smart home actuators and sensors on a demonstration wall and tested two smart home hubs, one open-source and one commercial product, which could both be combined with different devices from various manufacturers by using the most common wireless smart home communication protocols (Wi-Fi, ZigBee, Z-Wave, and EnOcean). The different components of the lab demonstrator and their interconnection are visualized in Figure 19.8.

19.5.1 Base Applications of the Standalone Smart Home

The standalone smart home hub can be connected with multiple sensors and actuators. When we selected these components, we did, whenever possible, choose low-energy devices, preferably devices with energy-harvesting functionality. Such devices use the available resources from the surrounding environment; for example, by using a peltier-element, the temperature difference between the radiator and the surrounding air can power a smart heating thermostat; the kinetic energy from pressing a switch can power the internal wireless transmitter; and small photovoltaic cells can provide energy for multiple sensors gathering and transmitting indoor climate data. All sensor data is collected within the smart home hub and an internal “if this than that” (IFTT) logic leads to actions being sent to other smart home devices or the user. Depending on the number of installed components, different energy-related routines are included. We clustered these individual routines, which led to four different states

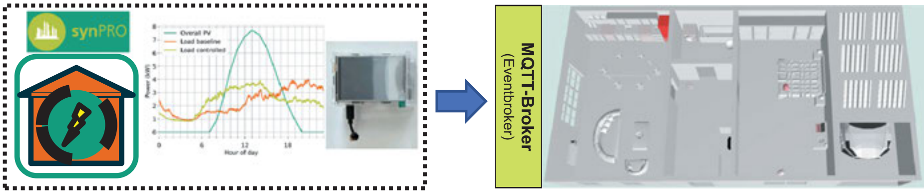

Figure 19.7: Smart home simulation, including synPRO smart home application simulation (left) and visualization (right).

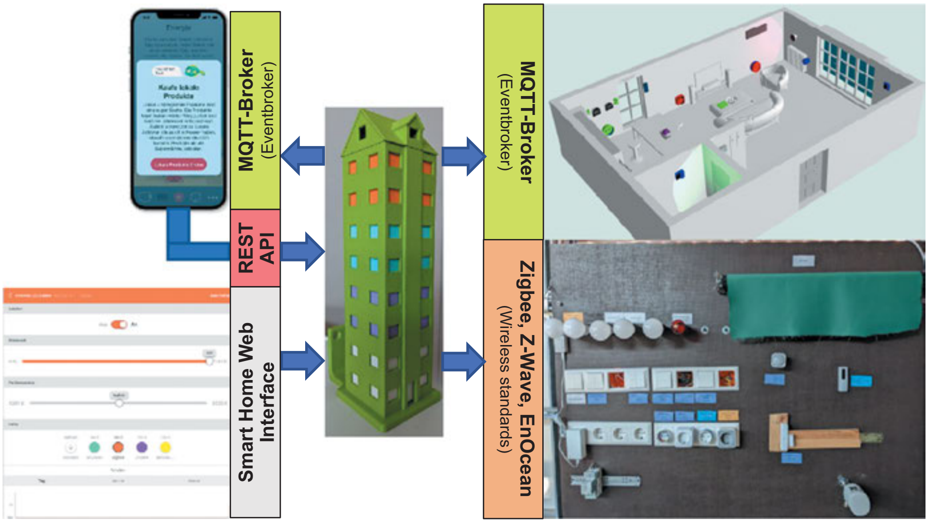

Figure 19.8: Lab demonstrator, including a smart home hub (center), smart home actuators and sensors on a demonstrator board (bottom right), a digital representation of the demo board (top right), the Fish ’n Tipps energy-saving app (top left), and the standard smart home web interface (bottom left).

(“at home”, “sleeping”, “away”, “on vacation”), which can either be triggered by automated events or by a manual action (e.g., by pressing a switch when leaving the home). A state change checks the current sensor data and predefined user settings to execute a variety of actions. Since explaining all routines within this article would be too ambitious, we will only explain one switch of states to show the general logic and give an overview of some practical IFTTS.

The initial state is “at home”; the room temperatures are set based on predefined user settings; the shutters are open; the air circulation rate within the occupied rooms works at a normal rate. Room climate sensors are monitoring the state and readjust actuators if needed. Now a user leaves the apartment, which is detected by the door sensor in combination with 10 min of no movement being detected or by the user actively pushing a switch upon departure. The state changes to “away” and the following actions are taken:

- **Electricity:** All predefined sockets are turned off, reducing the electrical demand to a minimum and only supplying freezer, refrigerator, and devices added by the user to an exception list. Additionally, the lighting is turned off.
- **Heating/Cooling:** The room target temperatures are adjusted to reduce the demand for heating and cooling. Additionally, sensors detect solar radiation and the smart home hub predicts the current thermal gains due to solar radiation. If the target temperature is below the current temperature (cooling demand), the shutters are closed. If the target temperature is above the current temperature (heating demand) and solar radiation is high, the shutters are opened; otherwise they are closed.
- **Ventilation:** Air circulation is reduced to a minimum.
- **Non-energy-related extensions:** Security devices are turned on (e.g., cameras or window/door sensors). Depending on the cleaning schedule, an automated vacuum cleaner is activated.

19.5.2 Added Value Through Interconnection

While the standalone smart home system already provides some value, its potential can be significantly increased by connecting it to other data resources and apps in the Pfaff ICT platform. The previously presented state change from “at home” to “away” can be extended further. The process including interactions with other apps and services is visualized in Figure 19.9 and explained in the following lines. Right after the state change is initiated, the user’s calendar is checked for specific events. Additionally, the current GPS position of the user’s smartphone is collected. With these two sources together with an optional learning database, the time of return can be estimated. This estimation could be verified by sending a push notification to the user for verification and at same time providing suggestions for possible routines or asking for further commands; or the user can stay passive and automation takes over. For example, if, on a working day, no events are scheduled for this day, but the user’s GPS signal is in a different city, the application could ask the user to confirm a business trip and how many days it will take. Otherwise, if the GPS coordinates are within a specific area, no notification is sent.

The information about a current absence can further be referred to an interconnected energy management system (EMS), with the aim being to shift flexible loads to times of high photovoltaic (PV) energy supply. A detailed description of the agent-based EMS is provided in chapter 20: “Agent Based Energy Management and Blockchain Based Organization for Energy Communities”. This information is used to optimize energy usage within the personal energy system and the surrounding energy system of the neighborhood.

1. If the user plans to return in the evening and a heating demand is expected for the night, or if the user usually prefers to take a shower upon arrival, the EMS could decide to heat up the domestic hot water and heating system storage using PV energy to power an electric heating system (heat pump or heating rod), thereby optimizing the user's individual energy consumption. Using the information on estimated travel time for the return trip, the apartment can be heated up, providing the desired room temperature upon arrival.
2. If, instead, the user stays away for a longer time, or if the expected thermal demand is low, the EMS could use the information about lower electricity consumption by one user together with high consumption predicted for neighboring buildings to feed PV surplus electricity into the public grid, sharing it within the Pfaff community (see red sequence in Figure 19.9).
3. Finally, if the predicted neighborhood demand is also low, the EMS could use overproduction to charge electric vehicles or, if no other target device can be supplied, to store it inside a stationary home or district battery system.

Smart charging of electric vehicles, in particular, has a large flexibility potential within the Pfaff district. It can further be enhanced by also including calendar information about the user or direct parameters, like a target state of charge upon departure to reserve some battery capacity exclusively for additional PV electricity. Additionally, bidirectional charging could be included to discharge the battery in times of high demand and recharge it later at times with PV overproduction. Information on whether the user prefers using an electric vehicle at all or would rather switch to other means of transport can be provided by certain apps, such as a mobility assistance app within the Pfaff digital ecosystem.

While weather data is needed for a good PV energy forecast, the same information provides another useful addition to a smart home system. Using weather predictions, the heating and cooling process can be optimized, not only in terms of reacting to the current weather conditions by exercising shutter control, but also in terms of considering temperature and solar radiation forecasts. In this way, the heating temperature can be reduced before solar gains can heat up the room above the desired temperature. Especially for slowly responding heating systems during spring or autumn, an anticipative system can reduce additional heating or cooling demand.

Finally, the previously mentioned Fish 'n Tipps app is linked to the smart home system, analyzing smart home usage and providing useful information, not only for automatically optimizing energy usage but also for increasing the user's awareness regarding their energy-related carbon footprint and encouraging them to change their behavior and make it more sustainable. For heating systems, the app could check the target temperatures of different rooms and provide a hint to further lower the room temperature during absences.

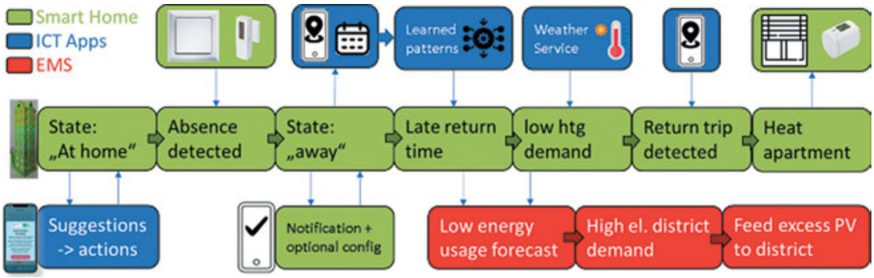

Figure 19.9: Example smart home sequence and interaction with the ICT environment.

19.6 Summary and Future Work

The digital transformation is able to support a climate-neutral smart city district in various ways. We started this chapter by explaining our general understanding of how this can be done and what the basic principles are in the development of digital solutions. We gave an overview of our digital ecosystem and described our platform and our mock platform, and presented several examples of prototypes, for example MiniLautern, the PfaffFunk app, and the Fish `n Tipps app. Here, data plays an important role as this is produced and consumed within the different apps. The district ecosystem is able to handle such data and takes care that qualities such as security or the GDPR is considered appropriately. Though we developed different solutions, they are part of one district ecosystems, which makes an integration easy. Of course, some of the applications, such as MiniLautern, is more a stand-alone solution, while apps such as the PfaffFunk or the Fish 'n Tipps app are deeper integrated and connected.

The presented smart home use case shows only a selection of possible interfaces between different applications and services. The more data sources are available, the more possibilities for smart automation emerge. The topic of machine learning, in particular, was only briefly tested by us with regard to user pattern analysis. When linking different applications within the ICT universe in order to reduce energy consumption and increase comfort, the topic of data privacy jumps into focus. For this study, we did not work on the network security part or on data encryption, but instead used an MQQT broker with clear messages displayed to be used by any service. Guaranteeing secure handling of personal data is a topic for a real–world implementation. In any case, the user can always decide what apps can access and provide what data and whether any synergies should be used at all.

The challenge of the slow construction work in the Pfaff district made it especially difficult to test our solutions in the district itself. This is one major open issue for future work.

References

Elberzhager, F., Mennig, P., Polst, S., et al. (2021) *Towards a Digital Ecosystem for a Smart City District: Procedure*. Results and Lessons Learned Smart Cities 2021, 4, pp. 686–716. Available at: https://doi.org/10.3390/smartcities4020035 (Accessed: 30 April 2022)

EnStadt:Pfaff (2019) *Leitbild für die Entwicklung des Pfaff-Quartiers Kaiserslautern.* Available at: https://pfaff-reallabor.de/site/wp-content/uploads/2019/10/0.4_190716_Leitbild_EnStadt_Pfaff.pdf (Accessed: 30 April 2022)

Surmann, A., Bär, C., Heupts, S., et al. (2019) *EnStadt:Pfaff Bericht: Meilensteinbericht M1 im Arbeitspaket 2.2.4 „Smart Home Anwendungen“*. Available at: https://pfaff-reallabor.de/site/wp-content/uploads/2020/04/191213_Meilensteinbericht_1_Pfaff_AP224.pdf (Accessed: 30 April 2022)

Fraunhofer ISE (2022) *SynPRO – synthetische Leistungsprofile für Wohnen und Gewerbe*. Available at: https://ies03.ise.fraunhofer.de/synpro/ (Accessed: 30 April 2022)