Zero Configuration Comfort and Accessibility in Smart Environments

Abdulkadir Karaagac(✉), Nicolas Coppik, and Rhaban Hark

ABB Corporate Research, Ladenburg, Germany
{abdulkadir.karaagac,nicolas.coppik,rhaban.hark}@de.abb.com

Abstract. By enabling more personalized hospitality services and adjustment of smart environments, the personalization of building and home automation systems can create better comfort, eased accessibility, improved user experience and greater energy efficiency for living and working environments. However, there is a lack of automation in nowadays systems, such that users must perform tedious manual interaction with the smart environments in order to personalize the environment according to their preferences and needs. In this regard, this paper presents the concept of *Zero Configuration Comfort and Accessibility*: portable and personalized smart space profiles which can be (i) configured, (ii) stored, (iii) accessed, (iv) transferred, and (v) applied to any smart environment in an automated manner. In addition to the concept, the main technical challenges and solution approaches for achieving portable personalization in smart spaces are presented. Moreover, the paper provides details about the design and implementation of a system prototype which demonstrates the feasibility and value of the proposed concept.

Keywords: Smart buildings · Personalization · Portable profiles · Building automation systems

1 Introduction

As smart environments and devices are becoming more capable and more common, people are expecting and demanding more personalization and increased comfort from smart environments. The personalization of smart environments includes the application of personal environmental preferences (such as temperature or lighting settings), automated routines, control, and/or accessibility requirements (voice commands, visual enhancements). The collection of these personal preference settings are referred as a *profile*.

Similarly, as many advanced technologies and systems, today's building and home automation systems are less accessible to people with disabilities, due to limitations of user interfaces and accessibility technology. Especially, considering the fact that smart environments are typically used by many different people, they are therefore usually not adapted to individual accessibility needs of users.

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This limits the benefits and usability of smart environments for people with disabilities.

Therefore, this work investigated the portable personalized profiles for smart environments and proposed the concept of *Zero Configuration Comfort and Accessibility* (*ZCCA*) which can enhance the accessibility, comfort and user experience in smart environments, especially for people with disabilities by enabling barrier-free and human-centered automation systems for smart spaces.

This paper is organized as follows. Section 2 describes some of the main use cases that the proposed concept can offer for social good. The key challenges that needs to be addressed to realize the proposed concept are presented in Sect. 3, which is followed by the potential solution approaches for those challenges in Sect. 4. After that, Sect. 5 provides a detailed description of the developed proof-of-concept. Finally, Sect. 6 concludes the paper with a short summary and outlook.

2 Use Cases for Social Good

The proposed concept of *Zero Configuration Comfort and Accessibility* (*ZCCA*) is the idea of portable and personalized smart space preferences which can be (i) configured, (ii) stored/accessed/transferred, and (iii) applied to any "smart" environment. By doing so, this concept enhances accessibility, comfort and user experience in smart environments, e.g., for people with disabilities, and deliver high-quality, barrier-free and human-centered home or building automation systems and applications.

Many technological advancements are less accessible to people with disabilities, including the usage of the Internet and smart devices [7], due to limitations of user interfaces and accessibility technology. Smart environments face another challenging development in this context, as they may be used by many different people and are therefore usually not adapted to individual accessibility needs. Apart from that, individuals may interact with a large number of smart environments on a regular basis and configuring each environment for their requirements is both practically challenging, given lack of accessibility, and would also present a large burden for environments that are only rarely interacted with. The proposed concept aims to address these concerns by making personal preferences and accessibility requirements easily portable and applicable across different smart environments. In the remaining of this section, three simple use cases are introduced to showcase the concept's application.

2.1 Personalized Spaces

The primary use case is the automated adaptation of environmental settings based on user preferences without requiring manual configuration of that environment, for instance in hotel rooms or office environments. By means of the proposed concept, the visitor's profile can be preloaded to the control system or automatically transfered upon their arrival, and the environment can be prepared based on their preferences and their type of trip. As this enables automatic application of personal preferences (profiles) to different smart environments and removes the need for manual configuration of control systems, thereby the *ZCCA* concept can enhance the comfort and accessibility of the smart environment and reduce the hurdles faced by people with disabilities in interacting with such environments. These personalized profiles may include environmental preferences (personalized control for temperature, humidity, light level etc.) and automated routines (alarm clock, lights, and heating cycles).

2.2 Personalized User Interfaces

In addition to environmental preferences, another aspect that can be personalized is how the user interacts with the smart environment: user interfaces for home/room/building automation systems. The user interfaces are one of the main components of smart environments which defines the usability and accessibility of the systems. A user may encounter several different smart environments, each with a different set of controllable devices and means to control those. At the same time each user has very individual capabilities (e.g. limitations due to disabilities, language) and personal demands when controlling smart environments. Therefore, temporary users of such systems typically first need to familiarize themselves with the interface, taking time and effort. If the controls are too complex, smart environment features may go unused.

The proposed concept can enable users to use their personalized interface to control any smart environment they encounter. This could include the customization of interfaces or presentation of unified user interfaces across different environments to improve the usability of the control/automation systems, especially for environments which are encountered only for short times. Also control capabilities can be adapted to the personal preferences and limitations of the present user by downloading a machine-readable description of those from a carried device or from a cloud share. Or, as illustrated in Fig. 1, control capabilities can be activated/deactivated and interface presentation can be adjusted based on the provided user preferences.

For instance, fonts sizes or altered colors in user interfaces for users with limited vision, changing language based on user preference or adjusted complexity level of the control functionalities. By offering personalized user interfaces, this concept can help to increase the acceptance of controllable smart environments, thus, also increased visibility and reputation of such systems.

2.3 Personalized Accessibility Method

Another aspect that can be personalized in a smart environment based on user profiles are the accessibility methods that user prefer or need. Based on the transferred accessiblity requirement information available in the user profile, different

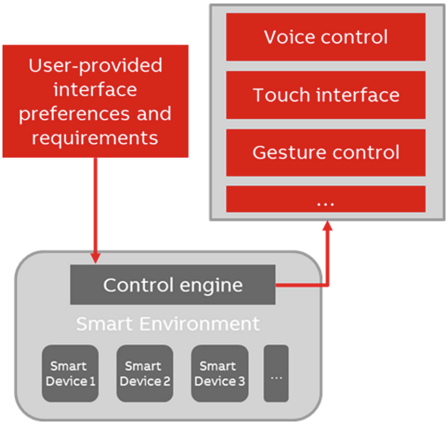

Fig. 1. User Interfaces adapting User Preferences and Accessibility Needs.

accessibility method can be activated or deactivated: e.g. voice recognition control for visually impaired users or visual enhancements for hearing impaired users.

3 Key Challenges

This section highlights some of the technical challenges that need to be addressed in order to realize the proposed concept of *Zero Configuration Comfort and Accessibility* (*ZCCA*) in smart environments. Potential approaches to the given challenges are discussed in the subsequent section.

Profile Portability. First of all, it is required to have appropriate means to make personal preference settings, so called profiles, portable. To this end, the profiles must be stored, transferred, and exposed in a secure and privacy-preserving manner. Within that a number of further sub-challenges arise. On the one hand, profiles should be always available with as little effort from the user as possible. Now, on the other hand, high availability options, such as cloud-based solutions, typically introduce considerable security efforts compared to manual transportation of profiles, e.g., in handheld devices.

Information Modeling. The modeling of the profile information is a twofold challenge: *(i)* First, it requires a suitable standardized, yet extensible meta-model for potential keys and values with accurately defined units. The model must be standardized (or be a candidate for such) in order to allow for interoperability of different systems and to prevent vendor lock-ins, a crucial acceptance criteria. On top of this, the meta-model must be extensible to allow for new and custom smart devices. The meta-model should additionally be organized in a hierarchical fashion to allow settings to be inherited from higher-level settings: As an example, the bedroom temperature can be refined, e.g., with a lower setting, while it also inherits the default room temperature in case it is not refined. *(ii)* Second, the stored per-user models must differentiate between different environments which a user may encounter. Within that, environments should also inherit settings from each other in a hierarchical fashion. A potential example here is the reuse of a home environment profile so it can be applied in a hotel room or office environment, without any special configuration if that is not desired.

Secure User Identification/Authentication and Access Management. In order to personalize the environment for user preferences, one of the main steps that needs to be taken is identifying the user and retrieving user-related data. For that reason, the presented concept and system requires appropriate methods to identify and authenticate users as well as provide access to selected data towards the smart environment. Again, this is a twofold challenge: *(i)* First, a user must be identified and authenticated through trustworthy means either by physical presence plus secret or using state-of-the-art online authentication mechanisms. *(ii)* Second, this includes the access to potentially privacy critical user profile for the environments encountered by the user. Thereby, the provided information may be limited to the extent required and configured for a certain environment.

Building Automation Systems Integration. Another key challenge is the integration of a *ZCCA* subsystem into existing building automation systems, where there is a plethora of different products. Besides a number of open-source solutions for building automation, several closed systems exist. Both need to be taken care of in order to ensure the user acceptance of the proposed concept and resulting system. Especially in the smart home sector, ensuring interoperability with the wide range of solutions available on the market poses a substantial challenge, which this work does not purport to fully address. Interoperability frameworks have been proposed as a solution to this issue [5], but have not seen widespread adoption. The adoption of the Matter standard may also indicate a move towards more standardized, interoperable solutions in the smart home space, which would alleviate this concern.

4 Solution Approaches

This section discusses potential approaches with their advantages and challenges. Those include the portability of profiles, user identification and how to model profiles internally.

4.1 Profile Portability and Storage

There are various options to store, transfer and expose preference data including cloud services, edge providers or directly on portable devices carried by users.

Firstly, a cloud-based service architecture can be an option. In this case, a central component serves as management unit and provides interaction between smart environment gateways and preference databases. The portability of the profiles comes from the availability of the data to all smart spaces via cloud access. An API (e.g., REST) as anchor point towards gateways and a web frontend allow access to the data. In case of any need for the modification of preferences, this API can be used by automation systems or by a web frontend.

In this approach, the created *ZCCA* system is available everywhere, highly reliable and not dependent on any particular device. However, as the preference data is stored in a cloud platform, care needs to be taken in order to address any privacy concern of users. Moreover, while the cloud service itself can be made highly reliable, overall reliability of the system also requires stable connectivity between a smart environment and the cloud service. A sample system architecture for such a *ZCCA* system with cloud-based services is provided in Fig. 2. As in Fig. 2, the cloud-based setup can include different backend vendors, allowing different environments to fetch preference settings from either of them after proper identification of a user. This design choice helps alleviate privacy concerns as users can choose between different backend services or even host their own.

Alternatively, an edge device, e.g., building automation system gateway, can also be used to store the user preferences locally (only and only with the consent of the user) and always close to the smart environment. This would eliminate the need of carrying a device and allow the system to work without cloud connectivity, but also limit the flexibility and availability of preference data cross different locations.

Thirdly, the profiles could be also stored and carried via mobile devices, such as smartphone, tablet or smartwatch. In this case, the data is carried together with the user as long as the mobile device is with them, which limits *ZCCA* functionality to scenarios where users have their device with them. However, the user data stays always with the user device, and the system can be designed to share as little data as necessary with the smart environment, making this a very privacy-friendly option.

After considering the advantages and limitations of these options for profile storage and portability, one can decide to use one of the cloud, edge or mobile-based profile portability solution or can also combine them to create more flexible solutions. In this case, the replication and synchronization of preference data needs to be handled carefully and properly.

4.2 User Identification and Access Management

Irrespective of where the preference data is stored and managed, users interact with the *ZCCA*-enabled smart environment locally, and user identification therefore also has to start with a local component. As the ultimate goal is minimizing user effort, this step should be as easy and convenient as possible.

A straightforward option for local identification of users is the use of hardware tokens, such as smart cards or phones, using Near-Field Communication (NFC) or Bluetooth Low Energy (BLE) beacons to detect a user's presence. As discussed above, some options, such as smartphones or more capable smart cards, can also be used to directly store preferences.

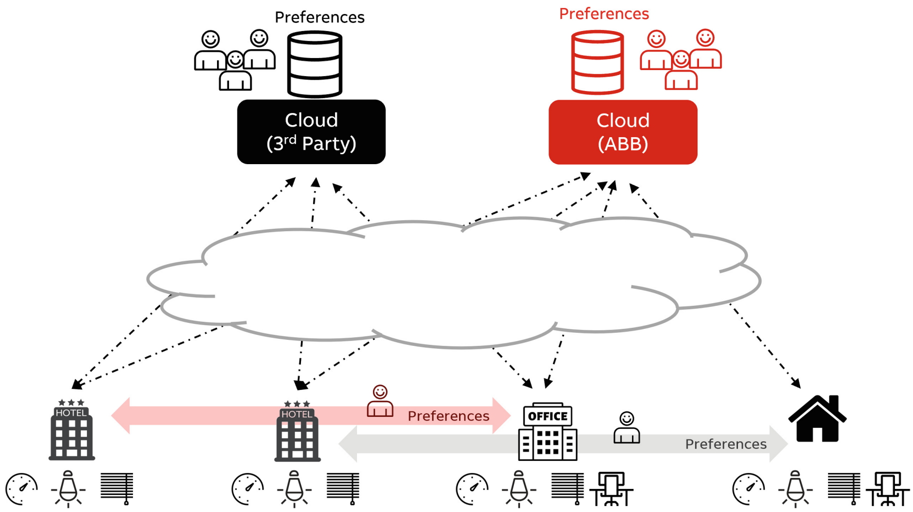

Fig. 2. Portable profiles using a Cloud-based Service Architecture. Two cloud backends are available from different providers. Multiple environments can access the backends.

Other options include biometric user identification, which may introduce privacy concerns, or, especially in enterprise environments, the integration of *ZCCA* concept with existing information technology (IT) infrastructure - for instance, in an office with desk sharing, users can be identified when they plug in their laptops, allowing their preferences (e.g., desk height or other ergonomic preferences) to be applied automatically.

In solutions using cloud or edge services to store and manage preferences, no matter what option for user identification is chosen, it must then be used to authenticate the user towards the backend service. The details of this process vary between options for user identification. A more detailed description of one example is provided in Sect. 5.3. Once the user is authenticated, their preferences can be retrieved from the backend service and applied to the smart environment.

Finally, all solutions must provide a way for users to manage their credentials, such as enrolling a new phone or revoking access for a lost smart card. Cloud-based solutions can easily provide this functionality as part of a web interface that users can also use to manage their preferences.

4.3 Information Modeling for Profiles

Looking at the information modeling for profiles, thus, for preference settings of users to control smart devices, a number of efforts already exist, which are targeting the modeling of Internet of Things (IoT) devices. To avoid the creation of yet another meta model, this paper refers to works such as HOMEML [6,8], the IEEE 1452.2 [1,10] and its adoption in IEEE 21450 [2], or IOT-LITE [3,4] as discussed in W3C. The interested reader may find more information summarized by da Silva and Hirmer [9].

As discussed in Sect. 3, the profile models must discern not only between users, but also environments and within that, allow to inherit settings. Environment settings can be inherited from other environments, e.g., *hotel* environment settings can inherit settings from *home* environment settings.

Furthermore, settings within an environment can inherit from one another. For example, room temperatures within one environment can get a default settings, but be refined based on their properties (cold bedrooms vs. warm living rooms).

In order to represent preference settings according to these requirements, this work set up a simple schema for settings depicted in Fig. 3. The schema exists per-user, while user settings are strictly isolated. For each user, all default settings can be set in the top level environment. Apart from this environment, sub-environments can be specified which inherit all settings from exactly one other environment. In each environment all settings can be individually configured or unset to cancel their inheritance.

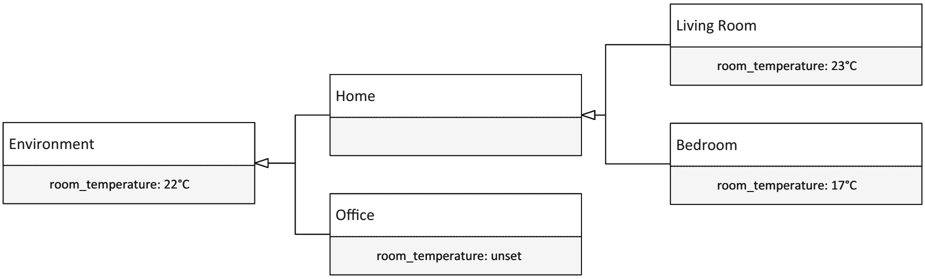

Fig. 3. Modelling of User Profiles based on Inheritance among Environments.

As example in the figure, the `room_temperature` is set initially with a default value of 22 °C. In the next layer, the environment splits up in a `home` environment and the `office`. Since the `home` environment does not refine the `room_temperature`, it will use the inherited 22 °C. The `office` environment unsets the `room_temperature` such that no value is given and the smart environment may apply any temperature, e.g., the company's default office temperature. Furthermore, the `home` splits up into different locations (sub-environments), namely the `living room` and the `bedroom`. In both cases the `room_temperature` value is refined with a low temperature of the bedroom and a more comfortable, warm temperature in the living room.

5 Proof of Concept

In order to demonstrate the feasibility of the *ZCCA* concept, a simple prototype is developed, which presents the capability of automated adaptation and personalization of smart environments according to portable user profiles. This section provides details about the created system setup, architecture and resulting demonstration flow.

5.1 Demo Setup

In the developed prototype system, a smart office environment with multiple control capabilities is mimicked. Within that, two separate working spaces with independent and different control systems and slightly different control functionalities are considered.

In the office environments, depicted in Fig. 4, the following control capabilities are integrated to enable accessibility and comfort: Both environments, *Workstation 1* (WS1) and *Workstation 2* (WS2), are equipped with a height adjustable desk such that users can sit with different heights, e.g., for office chairs but also wheelchairs as well as standing up. On top of this, one of the environments, namely WS2, has also smart control capabilities for the lighting, temperature and shutters. Both environments have an Radio Frequency Identification (RFID) reader for the purpose of identifying the users and therewith fetching their profile.

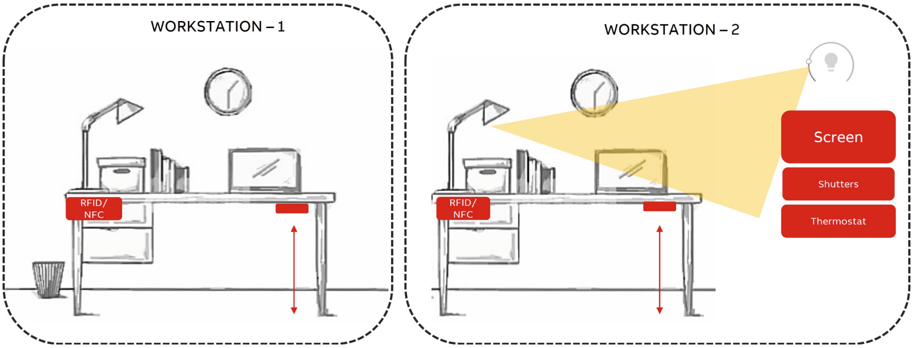

Fig. 4. Demo Setup to showcase a Proof of Concept for *ZCCA*.

5.2 System Architecture

Using the aforementioned setup, an automation system is created which can identify the user, obtain the user preferences, and apply those preferences on the desk height and other environmental settings.

In this *ZCCA*-aware automation system, a Cloud-based Service Architecture approach and deployment is used due to the omnipresent availability of profiles using this approach. The overview of the system architecture is provided in Fig. 5.

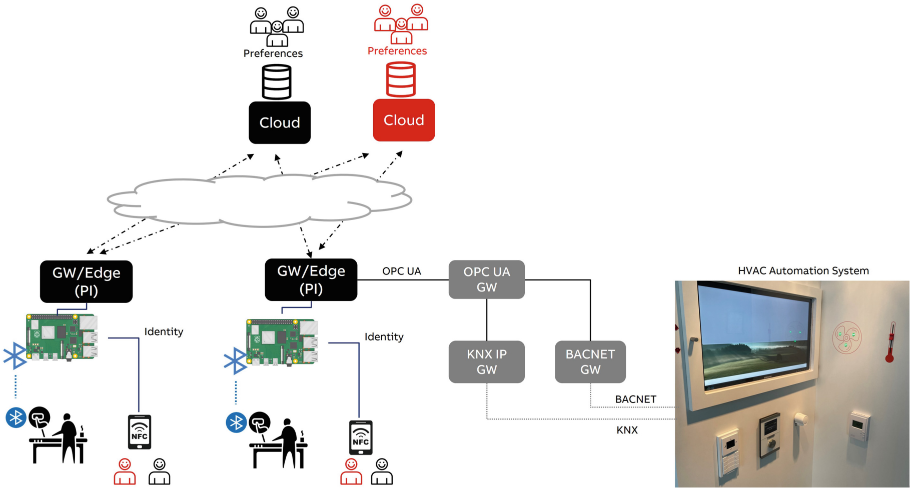

Fig. 5. The Architectural Overview of developed Proof of Concept.

As it is demonstrated in this figure, the setup includes two cloud instances (backend) which are being used by different users to store and access user profiles. On the other side, two local deployments with separate Gateways (e.g., edge devices) are created for each workstation: WS1 and WS2.

For WS1, the height-adjustable desk is integrated to the control system via *Bluetooth Low Energy* (BLE) and a smart card (i.e., NFC/RFID) reader that is directly connected to the gateway, which is used to identify the users. For WS2, in addition to height adjustable desk and smart card reader, a *Heating, Ventilation, and Air Conditioning* (HVAC) automation system is integrated by means of various industrial connectivity technologies (i.e. KNX IP and BACNET). This HVAC system allows the control of temperature, light and shutter system for the corresponding workstation.

5.3 User Identification and Access Management

The demo setup uses smart cards as user credentials, specifically Mifare Classic cards due to their broad availability and low cost. When a user presents their card to the system, the process shown in Fig. 6 starts.

First, the reader reads the card unique identifier (UID) and, since the system supports multiple, independent cloud instances, the URL of the backend service to use. This URL is stored on the card during credential enrollment, along

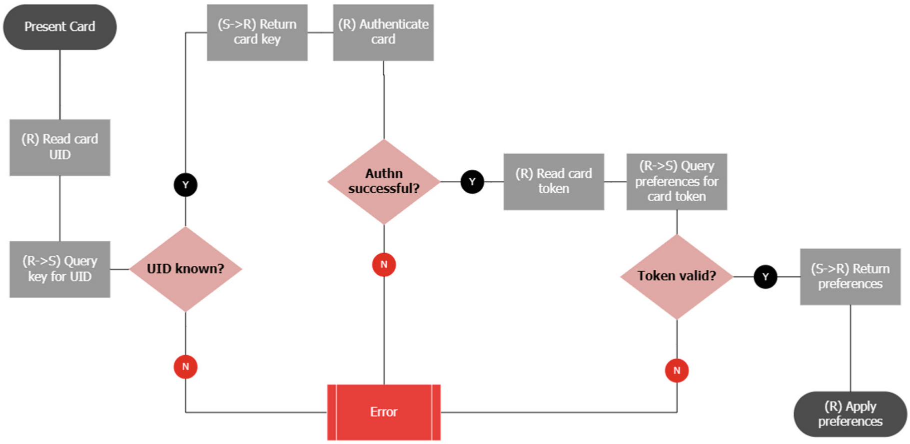

Fig. 6. Prototyped User Authentication Process.

with a unique token for that particular card generated by the backend service. The local system queries the backend service URL stored on the card for a key associated with that card's UID. If the service knows the card UID, it returns a corresponding key, which the reader can use to authenticate the card. From the authenticated card, it can then read the card-specific token. That token is sent to the backend service, as part of a request for the user's preferences. If the token is valid, the backend service returns the user's preferences, which can then be applied to the smart environment.

While the prototype implementation simply uses random bearer tokens, arbitrary other token formats could be supported. Similarly, although the prototype supports only a single kind of credential (classic smart cards), support for other kinds could easily be added. This would require implementing support in the backend service for the initial authentication steps, up to the point where the local system has access to the token. From this point, the token-based authentication and preference retrieval do not need to be adjusted.

5.4 Demo Scenario

The overview of the sample scenario and the demonstrated flow is illustrated in Fig. 7. As it can be seen in this figure, first, User 1 arrives to the working environment and checks-in to the workstation via the attached smart card reader and initiates the user identification process described in the previous subsection.

By using the acquired information (URL of the cloud instance, required credential data), the user profile is requested by the gateway from the corresponding cloud instance. Based on the user data and location information (specific location or its' type), the preference information is returned by the cloud server to the gateway.

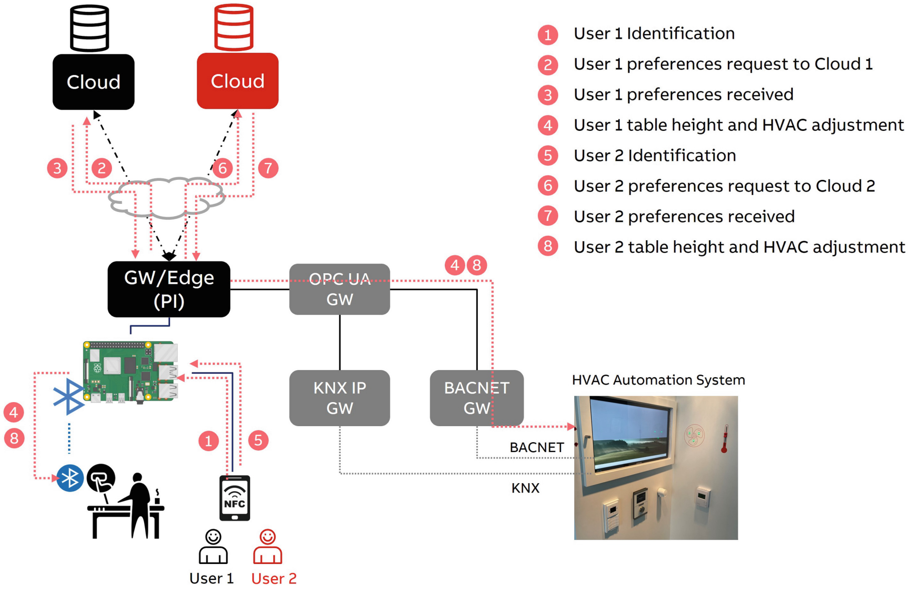

Fig. 7. Architectural Overview of the Demonstration Setup using two Instances of Cloud Services, a Gateway connected to the smart environment.

If the user information is not authenticated or if the access to the requested information is not granted by the user, the information request is declined. Upon the successful reception of the user profile, the environment settings and table height configuration is adjusted automatically. Some sample pictures from these steps and resulting changes on the proof of concept system is provided in Fig. 8.

Following User 1, another user identified as User 2, who utilizes an another cloud server, arrives and proceeds to check-in at the same workstation. By following the same automated procedures as for User 1, the same workstation is reconfigured according to the preferences of User 2. Similar to User 1, some sample pictures demonstrating each of these steps for User 2 are also available in Fig. 8.

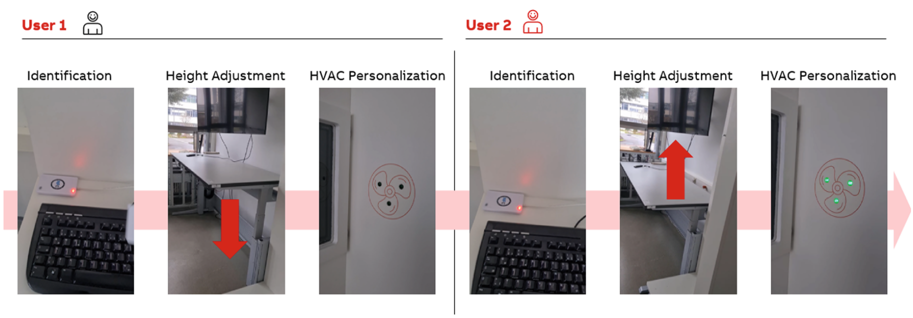

Fig. 8. Illustration of the Demo: The Environment adapts to the Profile that registered for an identified User.

6 Summary and Conclusion

Automated personalization and effortless adjustment of smart environments is an important step for improving the user experience and comfort for living and working. And it can enable to create more accessible, barrier-free and human-centered automation systems for smart spaces, especially for people with disabilities.

For that reason, this work investigated the feasibility and practicability of the proposed concept of *Zero Configuration Comfort and Accessibility* (*ZCCA*) which offers portable personalization in smart environments. A number of key challenges and research problems are identified. Consequently, the potential solution approaches for these challenges and problems are discussed. In summary, this includes *(i)* an architecture for storing and fetching user preferences, *(ii)* a concept for identifying users including access management for potentially privacy-critical profiles, *(iii)* a concept to model profiles with their relevant information. Last but not least, the conceptual architecture and description for one possible approach is detailed and a demo setup is created as a prototype to *(iv)* demonstrate the feasibility of the concept.

Even though this work takes an important step for more personalization, less configuration, improved comfort and accessibility, there are still a number of technical challenges that requires addressing. Especially standardized and widely adopted information models for user preferences, harmonized interfaces to enable interoperability and well-addressed privacy concerns will enable the true value of the proposed *ZCCA* concept.

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