

# Smart door as a solution for the independent life of people in need

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**Abstract** - The paper discusses the development of an IoT smart door application adapted to people with special needs, i.e. anyone who has difficulty opening the front door independently. Special emphasis is placed on persons with disabilities (PwDs) and on pandemic conditions. The new innovative application design is based on the principles of universal design in the broadest possible sense. All phases of application development are presented, from the idea of innovative and sustainable design of the application itself through the analysis of the needs of a wide range of potential users, various technical possibilities of implementation including all levels of communication, from proximity to 5G network, and application sustainability analysis. The design brings several innovative conceptual and technical solutions that contribute to the attractiveness, applicability and sustainability of the application.

**Keywords** - IoT, person with disabilities, smart doors, new design, universal approach

## I. INTRODUCTION

Safety is one of the priorities of persons with disabilities (PwDs) and other people with special needs, especially home security. However, home security in these pandemic conditions is taking on a whole new dimension. Therefore, the focus of ICT/IoT applications is necessarily shifting from mobility to security. Consequently, an application that provides maximum security of entry into the home with accessibility of use is becoming very popular. Such an application must have useful and useable solutions in accordance with several specific requirements. These specific requirements come from external conditions, predominantly determined by the pandemic, and internal conditions, determined by the limitations of people with special needs. Additional essential factors that determine application challenges are reliability and massiveness. An application that has the potential to respond to these challenges must be a completely new IoT-based residential entry control application, even more, an application that is far beyond the front door control.

The second chapter presents a concise analysis of the market with an emphasis on the user structure and defines the target application. The third chapter describes the challenges of the new application. The functional model is described in Chapter four. Chapter five provides an overview of alternative designs of targeted IoT app. In conclusion, the most important elements are summarized and guidelines for further steps are proposed.

## II. CHANGES IN THE STRUCTURE OF PwDs NEEDS

There are two main drivers of change in the market for services for PwDs, and both strongly support the development of IoT applications for them. The first is a general social trend of lifestyle changes marked by an aging population, an increase in the number of PwDs and an increase in the number of single households. The second trend is very new and is marked by pandemic conditions - that is the change in life priorities of PwDs and the elderly.

### A. General social change

A significant part of the world's population are PwDs and children with disabilities [1], [2], [3]. The global trend increases their share in the total population. Another significant factor, which is partly related to disability, is the global trend of population aging. It is one of the most important social changes of the 21st century that has an impact on almost all sectors of society. The trend is shown in Figure 1. showing the median age of the population, i.e. age at which 50% of the population is older and 50% is younger, in some of the most significant countries considering GDP, ranking by IMF [4], [5].

The change in the way of social life greatly affects the number of single households that have the highest growth trend in the world. They are followed by the number of two-member households, while the number of multi-member households is constantly declining as it is shown in Figure 2. [6]. Such a situation leads to the impossibility of self-care for the elderly and PwD, so they are forced to leave their own home and settle in institutions. This is contrary to the WHO recommendation that older people as well as PwDs live in the community as long as possible and that they join institutions as late as possible to foster a sense of independence and mental health. There is also a UN recommendation from 2007. that families of persons with disabilities should be equipped with the resources to provide adequate care and avoid institutionalization. One of the more significant problems for the possibility of independent living is that the elderly population as well as PwDs due to their chronic illnesses or acute health condition are not able to either open the door (e.g. bedridden) or decide whether to open the door (for example due to mental illness or intellectual disability). Also, with this group of PwDs the entrance and the exit control and is significant for their guardians in case they do not return in the expected time [2], [3].

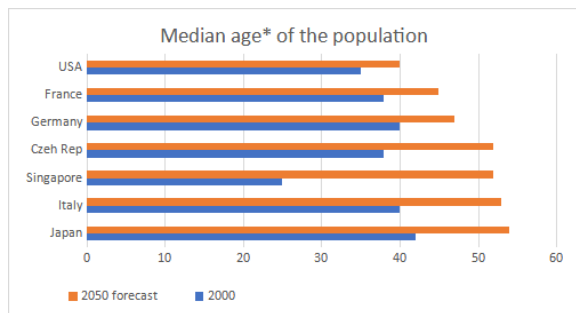


Figure 1. Median age of the population

### B. Changing priorities under the impact of a pandemic

In the last year, almost the entire population of the Earth has been changing its priorities under the influence of pandemic living conditions. However, there are more and more social analyzes that indicate that these trends will last longer, and that they will largely have a permanent character. This change in priorities and trends has several significant features. The first (1) is to reduce the need to move outside. There are two main reasons for this: the risk of infection as the risk of bad consequences of the infection and the general closure of social activities. Another important factor (2) is increase of the need for isolation, i.e. self-isolation (voluntary and preventive). In such conditions, some specific needs and problems erase. The avoidance of living together in special purpose homes is increasing, which means that, more importantly for these considerations, the need for independent living in one's own home is increasing. There is a growing need for as few physical contacts and visitors as possible, and a need for physical security. Finally, perhaps most importantly, there is a growing need for a general sense of security and a reduction in feelings of loneliness and isolation. On the other hand, the logistical problems of supply, maintenance of living space, health care and nursing in the conditions of significantly reduced social contacts are enhanced.

### III. CHALLENGES OF THE NEW APPLICATION

Because of described world situation the focus is shifting towards home security which is starting from the front door. Front doors should not only provide security from the entry of unwanted visitors but also to provide functional support for their independent living. All this set up completely new challenges for smart door applications.

Existing smart door applications generally work as ICT copies of special-purpose devices such as intercoms or

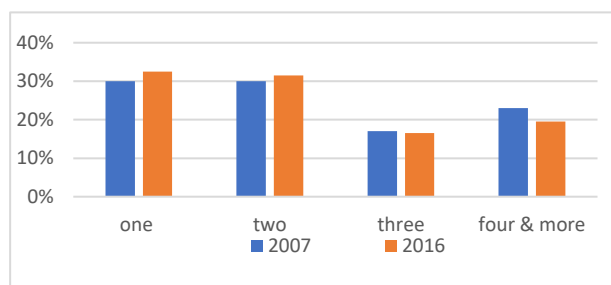


Figure 2. Household distribution EU-27

other similar pre-existing solutions. There is on the market a smart lock and smart doorbell solutions with their connectable applications, but they work in a limited distance connected by wi-fi [6] and are relatively expensive, especially for our targeted population. Additionally, they require the installation of special devices and cameras. There are some solutions that use mobile devices but are functionally insufficient [7]. However, only few of these solutions are adapted for people with motor, visual, hearing or cognitive difficulties but they do not respect the principles of universal design. In addition, existing smart door applications often come on the market in the "Smart Home" application package, which gives some applications that users do not need or are not interested in. Price of such "Smart Home" is higher than for a single application. The application package must necessarily work with functional compromises of its parts to cover the breadth of needs, but with very little consideration of the actual needs and capabilities of users. This is especially noticeable with PwDs. In general, the current state of development of ICT and IoT applications is driven more by the fascination of technical progress than by the needs of users. Current solutions do not meet their needs due to several reasons. Adapting applications to PwD mainly comes down to limited interface adaptation (larger letters, louder sound), which most such users are not satisfied with (especially the group with mobility difficulties and mental problems). Use is overly complicated, and usage on the user interface side is too limited. Also, it does not solve the problem of feeling insecure when letting visitors into the space.

So, the first step is gathering requirements, understanding the users and their goals via naturalistic observation, limited survey among potential users, focus groups and interviews. Some interesting and unexpected results are emerged; set of their needs are reduced compared to users without difficulties. On the other hand, these needs are qualitatively significantly higher than for others. Considering the issue of the needs of PwDs, we conclude that controlling entry into their space is high on their list of priorities. This is further noticeable at the time of the pandemic because PwDs are at high risk and have a heightened sense of fear of the disease in general.

Due to all the above, an adequate application should achieve the following requirements:

1. To increase the user's feeling of security, and reduce user's the sense of isolation, loneliness and abandonment himself,
2. Customizing the user interface to multiple PwD needs,
3. Easy and intuitive use,
4. To provide more alternatives of realization according to specific user preferences,
5. Expand communication possibilities on user's side in order to ensure fast and reliable interaction,
6. Reduce the cost for PwD users.

As the biggest challenge for the application of smart doors, we see the need of users to increase the feeling of security, reduce the feeling of isolation and loneliness and

TABLE I. APPLICATION USER STRUCTURE

	User Type	User Description	User Quantity	User Status
1	Client	Persons in need of remote management of the front door.	1 (only 1)	Registered
2	Guardian	People who make decisions for the client	1 ... few (limited)	Registered
3	Visitor	People who have the need / desire to open the doors of clients.	1 ... many (unlimited)	Registered / Unregistered (guest)
4	Door	Entrance or any other door in the client's space.	1 ... few (limited)	Registered
5	Data warehouse	Keeping records of all events related to the client's smart door.	1 ... few (limited)	Registered

left to himself. Technical improvements and major technical adjustments to the user can contribute to this, but they are not enough. An additional technical possibility is to increase intelligence of user devices. One logical continuation is the step towards AI and towards the virtual assistant. However, such a solution should be carefully introduced. PwD population and elders prefer physical social interaction and are difficult to adapt to the standard interface of virtual assistants. They have little confidence in technique and are difficult to accept "high-tech" solutions. Probably the most significant problem is that virtual assistants are generally not tailored to the needs of PwD (similarly to existing ICT applications).

In such conditions, an innovative solution that maximally solves these obstacles is a personal assistant in the form of a guardian. The guardian is a person trusted by the beneficiary - adult children, siblings, friends of great trust, social workers or others who can and may take such responsibility. The role of the guardian is to take the decision in circumstances when the user himself does not want or cannot make a decision to let the visitor into his living space. The physical location of the guardian doesn't matter. Another important element is the recording of visits and visitors, that are stored in the cloud, and are available to the user, guardian(s) and others authorized by the user. Cost is basically non-functional requirement, but very important for PwD users. In addition to meeting other needs and applying a guardian solution, the application has a clear sustainability potential for the target group. But, research among users has shown that there are four additional groups of users, and in total there are five target groups:

1. PwD, especially those with mobility difficulties and mental issues (approx. 550.000),
2. Persons who do not have the status of disability, but have real needs due to chronic movement problems or mental problems (estimate 140.000),
3. Acutely ill persons who, due to their current, but not short-term, condition, have problems with access and control of the front door (approx. 30.000),
4. Persons who for special reasons, such as a pandemic, they want to limit their contact with outside parties (there are no figures for now, but there are, estimate 100.000),

5. Small children (6-10 years) i.e. their parents who want to have control of the front door while the children alone at home (approx. 120.000).

The data were obtained from the official website of the Croatian Bureau of Statistics [7], supplemented by a comparison with data from UN and UNESCO reports [8], [9] for category 2, and a free estimate for category 4. Furthermore, it must be considered that users are also visitors and guardians. So, the estimation of number of potential users reaches 1.000.000 users.

#### IV. FUNCTIONAL MODEL

For an application to be sustainable and successful, its functionalities must meet two basic criteria: it must be useful, and it must be useable. This means that the functionality of the application must meet the needs of its users to perform the desired actions and, secondly, that the functionality of the application allows the user to accomplish the task in an effective, efficient and satisfying manner. The functionality of the application depends on the needs of the users and their needs.

The primary or direct users are people with various types of special needs, from PwDs to small children (e.g. their parents), as already described. They primarily need for remote control, supervision and management of the front door. They are direct users of the application as well as guardians and visitors. Visitors can be delivery people, postmen, community care, social care, guests, and others. The stakeholders of the application are also doors, and data warehouses in which all data related to the monitoring and management of smart doors are stored and, if necessary, processed. Therefore, the complete user structure includes 5 groups of users shown in Table 1. To achieve their goals application must provide innovative functional solutions expressed through functional model and innovative technical solutions which are realized through user function scenarios.

The functional model has three levels of functionalities:

1. Basic functionalities: remote access to the door, control, monitoring and management of the opening i.e. entry into the client space
2. Additional functionalities: adapting the interface design and application functionality to customer possibilities, remote (guardian) door management including communication from remote locations, and predefining visitor entry permissions
3. Added functionalities: migrating smart door service from local devices to network IoT services, eliminating customers' need for special devices at front door, and the ability to have multiple doors within the same application and a wider range of devices connected with the door.

Basic functionalities meet the fundamental requirements of entrance door control. They are also a link to current solutions and existing applications and make it easier for users to adapt to new solutions. Additional functionalities allow users with special needs to use the application in multiple ways, according to their needs. They also represent elements of universal design which allows a

wide using. Added functionalities give added value to the application, making it more attractive and even closer to users with special needs. Also, by applying a universal design principle, they make the application attractive to all users.

Total needs and events can be described through 9 scenarios divided into 3 groups:

1. Fundamental user functions: (i) user registration and initial assignment of rights (client, guardian, visitor), (ii) user login (client, guardian, visitor), (iii) rights management (client, guardian), (iv) review of records (client, guardian, visitor),
2. Smart door management: (i) the client makes the decision to open the door, (ii) the client does not respond, the guardian makes the decision to open, (iii) the client does not want to decide, the guardian makes the decision to open,
3. Predefined entries: (i) the visitor entrance based on an announcement and a one-time permit, (ii) the visitor entrance based on predefined rights.

Scenarios and functionalities are not directly causally related. Each scenario relates to multiple functionalities. In this way, a modular structure of the application is built, which enables flexible development and implementation by elements.

The most significant group from the application functionality point of view is second group of scenarios and it must fully meet the useful and useable criteria. Functional use case diagram that describes a user's interactions with events and processes is shown on Figure 3. It represents all user types, both human and machines. The presented model shows all participants in the scenario as users of the application and defines all the objectives of the application for this group of scenarios. Furthermore, the operation of the application is seen, in all three scenarios of this group of scenarios from the side of the user perception.

The user uses a system management application on his mobile device. Existing applications require customizations for people with special needs and expanded functionality to include guardians. The application needs to communicate with the administrator's mobile device, which can be anywhere, using the resources of the user's local network or public wireless network. A database (that can

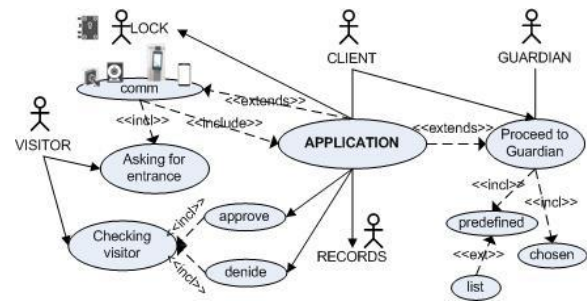


Figure 3. Functional use case diagram

be in the cloud) is used to store customer and event data on the door.

Observed by the user, regardless of the method of implementation, the application makes a call to the client. The client has the possibility to communicate with the visitor and / or the door and do or doesn't decide to open the door. In case the client decides to open the door, decision is implemented, and the data is stored in the records in the cloud. In case of disapproval of the door opening, the visitor may request communication with the guardian. If the client does not want / cannot make a decision, the request is sent to the guardian. The order of calls is predefined by the client and may involve several guardians. The client can make a call to the guardian beyond the predefined list. After the delegation of the decision to the guardian, further management is taken over by the guardian, with the possibility of communication with the client and the visitor. Users will have possibilities to set up basic features depending on their disabilities: type, color and size of font, background colors, voice control, size of icons, etc.

## V. ALTERNATIVE DESIGNS

Usage and event scenarios can be realized in a variety of ways, defined through alternative application designs. There are several possible technical solutions for this type of smart door application. We can reduce them to three basic designs:

1. IoT upgrade to existing entrance door control solution,
2. IoT based integration of entrance door control elements solution,
3. pure IoT network-adapted entrance door control with cloud-based solutions.

The communication platform for all three designs is a modular and scalable communication network supported by communication protocols from proximity to global wireless network including 5G network. It can also include a fixed network via the client's terminal equipment. An overview and description of the communication platform is given in Figure 4.

For the visitor, the starting point of the communication is the global mobile network, client's wi-fi network or WPAN protocol (bluetooth, zigbee). For the client, the communication platform can be home wi-fi network or a global mobile or fixed network. For the guardian, it is a

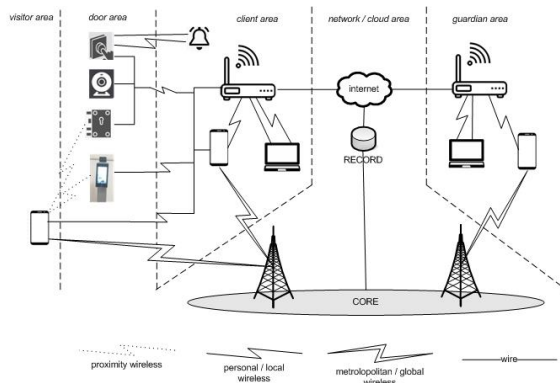


Figure 4. Application communication platform

global fixed or mobile network or his home wi-fi network. Both client and guardian have permissions to manage the door from client's space or remote.

Application operations is presented in Figure 5. It defines the responds of client or guardian to the entry request. Alternative solutions are presented separately for better clarity. Of the significant alternative events the visitor may entry by predefined entry rights, permanent or one-time pin or QR code, or by voice message or some other similar solution. All communication and control take place via the application, and the door is opened only by the lock. A similar procedure is defined for exit. The door as a stakeholder receives all commands from the application and executes it and sends feedback. The application records all relevant data, especially opening and closing times, audio and video communication. Record as a stakeholder is a cloud storage and application managed by service provider. Access to the records has a client, guardians, and others by court decision.

The differences between these solutions are in a way of communication between the users of the application and gives the possibility of flexible adaptation to the client's special and general needs, such as financial. Comparison of alternative designs is presented in Table II and Figure 6.

### A. IoT Upgrade Solution

This approach anticipates the use of a controllable electronic lock on the front door as a product already on the market, with minimal modifications, as shown in Figure 7. Such a lock uses a controller with a communication module and multiple output control modules. The client uses his own terminal devices that are tailored to his special needs. At the front door, a controllable electronic lock communicates with a mobile phone or other client's device using WPAN (e.g. Bluetooth, Zigbee) or wi-fi. The guardian uses his mobile device, which is connected to the client's device via a global communication network. The lock is equipped with a built-in or connected microcontroller that communicates with the user's local network via communication module using selected protocol. A wi-fi camera for visual and audio communication with visitors can also be connected to the

TABLE II. COMPARISON OF ALTERNATIVE DESIGNS

Activity	Application Solutions		
	IoT Upgrade	IoT Integration	IoT Pure Solution
Lock-door Interface	electronic lock with controller	electronic lock with specific device (SpDe) with controller, comm and M2M options (like a cellphone)	electronic lock with controller and M2M options
Visitor-door interface	doorbell with specific features	touch a SpDe	NONE
		close move in front of SpDe	
		proximity comm with the SpDe	
Guardian-door interface	via Client's equipment	via Client's equipment	
		WAN	
Visitor-client comm.	via doorbell	via SpDe	WLAN
	WLAN		
	WAN		
Client-door/lock comm.	doorbell with specific features	via SpDe	WLAN
	WLAN		WAN
Client-guardian comm.	WAN, automated	WAN; automated from client's equipment	
	WAN, redirected	WAN; redirected by client	
Visitor-guardian comm.	WAN		
	via Client's equipment		
Client-records	WAN		

system. Both the lock and the camera can be powered by their own battery (rechargeable or replaceable). The visitor comes and by pressing the bell sets a request to enter. The ringtone is registered by the client or its terminal device and the application is activated as shown in Figure 5.

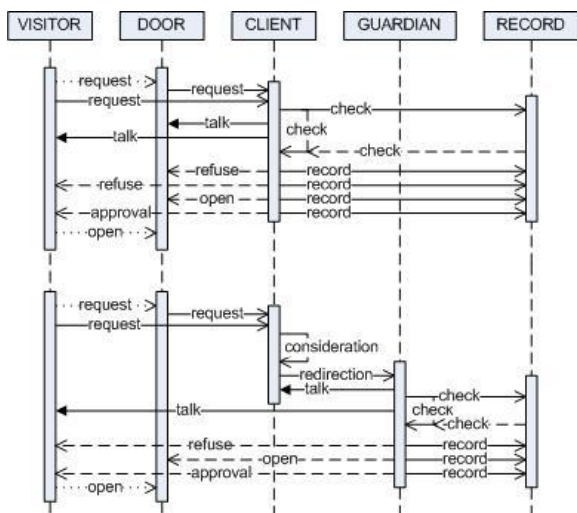


Figure 5. Application operation

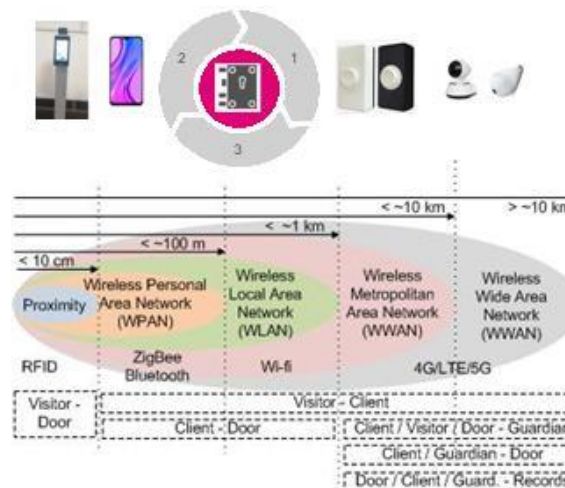


Figure 6. Design & scalability

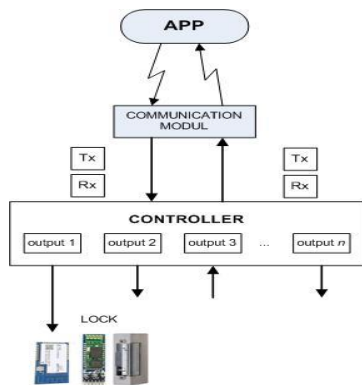


Figure 7. Controllable electronic lock scheme

This solution is based on a specific device on the front door. This specific device is similar to a mobile phone in its communication and some other features, and we can call it a "cellbell". It has a camera, supports data and voice communication with client and/or guardian devices, and controls the input lock. The communication solution uses client's equipment or directly from the device itself. Given the goals and features, it can also be a mobile phone appropriately adapted to this purpose. We use a controllable electronic lock on the front door, like the previous case. Cellbell communicates with the client's terminal equipment, and/or with the guardian. Depending on the equipment, it can use all levels of communication – proximity, wi-fi, global communication network. It can also be connected to a client router and an ethernet connection, which gives a lot of extra security. The power supply of such a device can be solved similarly as the power supply of a wi-fi camera, with its own battery (rechargeable or replaceable). Arriving at the door, the visitor "rings" in several ways - touching the device, sending a signal using proximity communication, bringing the QR code. Ringing triggers an entry request. Further communication goes between the cellbell and the client or guardian equipment. However, a higher level of management can be transferred to the cellbell. This gives more to the reliability of the system, remote communication with both mobile and fixed network, and if it is equipped with a SIM card can be independent of the client's equipment.

### B. Pure IoT Solution

The visitor selects the client on his mobile device and sends a request to open the door via the application. The application on the client's mobile device receives the request. Communication is established between the visitor's and client's mobile device. Based on predefined statuses, the application can decide to release visitors into the client space. If there are not enough positive statuses for such a decision, the application establishes communication with the client or guardian according to the already standard protocol. Depending on the capabilities of the device and the communication network used, this communication can be voice, video, image, or data. This brings additional quality in terms of safety.

## VI. CONCLUSION

The paper gives a detailed description of a new universal and innovative solution for smart door application that will be an integral part of a smart home in the future. The app is initially intended for PwDs but can be used by anyone interested in a smart home accessibility solution. Universality is based on the application of the principles of universal interface design, in technical solutions and especially in various features and wide possibilities of application. Innovation is reflected in several new features that are tailored to a wide range of users with a variety of special and different needs. The first element is reliance on the technology of the 4<sup>th</sup> industrial revolution (4IR). In the user part of the design, it relies on ICT /IoT technology with the maximum use of network technologies in the communication part. The application has an evolutionary feature, because of its modularity it can be easily adapted during further technological development. Reliance on modern and up-to-date technology is a key driving element of application design and the basis of other innovative solutions. The second element of innovation is the adaptation of the entrance door control procedure to people with special needs, and the third is the adaptation of the presentation that goes beyond previous solutions. Finally, the element that takes most attention is the role of the remote guardian.

There are a few more topics that need to be worked out. First is cost which depends on the chosen design but each choose with its functional solutions should reduce the cost of implementation for the users. The cost of use can be distributed in the regular cost of electronic communications services. Because of the social and economic status of PwDs and elderly population, the cost of smart door solution has to be subsidized by the governments or by telecom provider via ESF (European Social Fond). Security is also important issue that should be considered closely - privacy, cybersecurity attacks, network problems, power outage, etc. Currently solutions rely on network security and stability. In case of power or telecom outage, there is always classical solution – plain door bell, lock and key.

The most important next steps are development and presentation of prototypes and evaluation of solutions.

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