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Design and Implementation of Self-adapting Toilets for Semi-public Environments

Reflections on transferring a home solution to semi-public places

Paul PANEK*
Applied Assistive Technologies, HCI Group, TU Wien, Vienna, Austria
Peter MAYER
Applied Assistive Technologies, HCI Group, TU Wien, Vienna, Austria

Older people and persons with disabilities may face significant challenges while using a toilet. While assistive toilets at home can be tailored explicitly before or during installation to meet the individual needs and wishes, this approach fails in semi-public settings (restrooms in, e.g. restaurants, event locations or community centres). In this case, the users and their needs are not known beforehand, and thus the toilet needs to be capable of adapting itself. Based on previous successful Research and Technical Development work on prototyping an Information and Communication Technology -enhanced toilet for home use, the transfer of this concept and the necessary conceptual extensions for the out-of-home setting are outlined and reflected. Current findings show the wide variety of user needs and preferences and the different levels of technological affinity. The new toilet prototype system thus can provide different ways of physical support during toilet use and different levels of interaction, from basic to advanced, from non-complex passive use for novice users to more advanced functions for more experienced users. For example, it can retrieve previously saved settings, estimate height and detect falls based on 3D technology. A field test of the final prototype is being prepared for late 2022 to assess actual benefits.

Keywords: *toilet; adaptability; user interaction; ambient assisted living*

* Contact: **Paul Panek |** e-mail: paul.panek@tuwien.ac.at

Introduction and Aim

Even in Europe, the toilet situation for a significant part of the population is unsatisfactory. Astonishingly, in contrast to other areas of daily life, there has been little progress for disabled or older people in technical support for easier toilet use. However, this is a daily activity, and the problems are well known (Bichard and Hanson, 2005), (Hanson, 2007), (Kira, 1976), (Molenbroek, 2011).

Some advances beyond the simple Western-type toilet can be found in the home area: in the luxury segment with high-end electronic designs including biometric analysis and using a smart home toilet as a personal health assistant (Jaglarz, 2021), but also increasingly by basic stand-up support systems for home use and shower (bidet) devices (Jaglarz and Charytonowicz, 2015). In the area of public toilets, recently, the Changing Places (Changing, 2022) initiative for upgrading toilet rooms with changing benches and hoists for adults has emerged in the UK and very recently also in Germany (Toiletten für alle, 2022).

By default, for accessible toilets, it is mandatory to offer a fixed (raised) toilet height, which, as a compromise, does not meet the individual needs from body size, wheelchair use, and physical ability to stand up. This makes it difficult or even impossible for some people to use public toilets without personal assistance. The inappropriate height poses significant risks during autonomous use. Always having an accompanying attendant with you when leaving the house or asking other people for help in the toilet is certainly uncomfortable.

In the “iToilet” project (iToilet, 2018), we first worked on the idea of more intelligent, physically assistive toilets for disabled or older people at home. We can show the positive results from field tests with individual users whose needs, wishes and preferences are known. The semi-public (out of home) area poses additional difficulties since the usual method of customising the stand-up aid for each individual user (often before installation) is not possible. In contrast, in this area, a wide variety of unknown users must be served with excellent robustness. We set out to study a concept for such physically assistive products in the ”Toilet for me too” (T4ME2) follow-up project (T4ME2, 2022).

In other projects, we are also working on the cognitive support of people with dementia in the toilet area, another important field of research with major challenges in many areas (Ballester, 2022), (Panek, 2020). In the paper at hand, our focus is on the provision of physical support.

We also want to ensure that autonomous use without a support person being present does not compromise safety, so we included a component capable of detecting falls and emergencies and triggering automatic alarms (Lumetzberger, 2021) while respecting privacy of the user (Mucha and Kampel, 2022).

Our vision is to use modern Information and Communications Technology (ICT) in the form of innovative ICT-enhanced and safe toilet systems that adapt to the individual needs of users and enable older people and people with disabilities to participate more in societal life (Güldenpfennig, 2019), (Mayer, 2019), (Mayer and Panek, 2022), (Panek, 2017).

In this paper, we present findings from research activities and then reflect on the transfer of physically supporting toilet systems from home settings (project iToilet) to semi-public locations (project T4ME2) and the emerging design challenges.

Setting the Scene

Postures during toilet use

Many older but also physically disabled people report difficulties in the task of standing up from chairs (Chikai, 2021) and usual toilet seats (Hanson, 2007) (Kira, 1976). Therefore accessible ("disabled") toilets come with a higher toilet seat as a compromise, allowing easier stand-up for many people. This raised height during sitting on the other side weakens the stability of people with reduced strength as the feet (especially of people with shorter limbs) may not be flat on the floor to support the weight for stable sitting. At the same time on the other side, a too high position during toilet use can cause difficulties in defecation because of well-known biological principles (Sikirov, 2003). For sitting down, it also might be experienced as safer and more comfortable when the seat is in a relatively high position not requiring a large distance until the sitting position is reached.

The ideal toilet height thus differs for the different use phases (sit down, sitting, stand-up) and for different people, for most a low position is good for defecation and stable sitting but a higher position is helpful for easier stand-up.

Toilet stand-up supports and lift devices

On the market, we find several commercial devices for home use. For moving the toilet seat into the required position two methods are in use:

- A "chair" type construction, which can be simply put over an existing toilet bowl as an add-on. Here only the seat moves, not the bowl (see Figure 1).
- A wall-mounted construction, which replaces conventional toilet bowls and lifts the bowl (see Figure 2).

Some devices can only adjust the height (no inclination or "tilt"), seat always horizontal, "vertical" type), most chair type devices provide a combined height and tilt adjustment (fixed relation, especially "chair" type devices, "diagonal" type), only a few devices support the fully independent choice of height and tilt (Santis, A.S.T.).

Control of the height and tilt changes is generally provided in the form of physical buttons which offer simple manual "higher" and "lower" operations within the mechanical limits. Some devices can also be ordered with special remote control, e.g. for operation by foot.

Figure 1. Typical "chair type" devices: Santis R2D2, Economic Holland Aerolet, Solo toilet lift

Figure 2. Typical wall-mounted lift devices: Pressalit WC Lifter, Santis Silvercare, A.S.T. Lift WC

Research results on situation and needs

Users were involved via the user organisations participating in the projects, a mixed method approach was used for the study design (Mayer and Panek, 2017), (Pilissy, 2017), (Verburgt, 2021) combining qualitative and quantitative methods (e.g. interviews, questionnaires, online polls, focus groups). Main research questions were to explore the most important difficulties users do face when having to use existing toilets, the most wished / needed functionalities for better suitable toilets and the satisfaction with the tested innovative prototype systems.

Feedback collected during the iToilet project (involving visitors of an MS day care centre and patients of a rehabilitation clinic) confirmed that people are having many problems using standard and even barrier-free toilets when on their own (Figure 3).

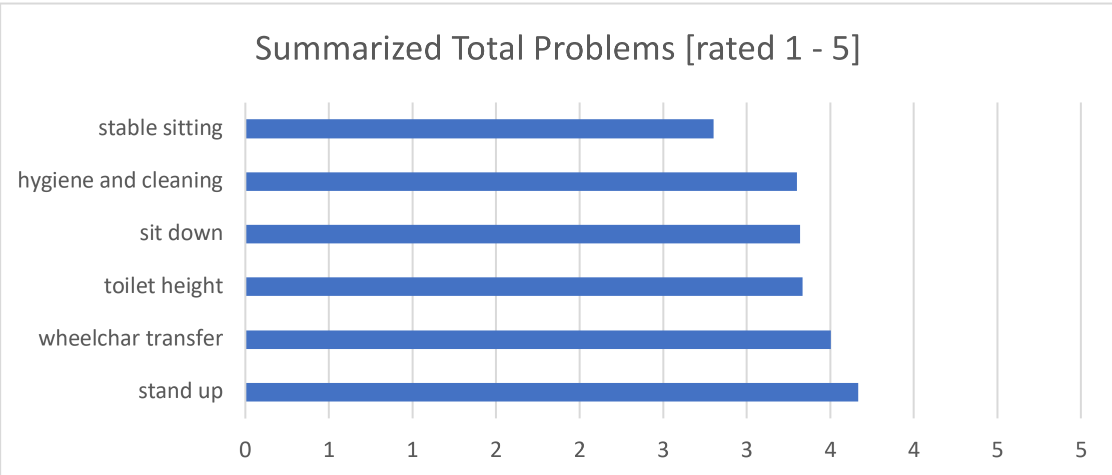

Figure 3. Summarised average ratings (1=low to 5=high) on toilet problems by all 74 primary, secondary and tertiary users (patients of a rehabilitation clinic in Hungary and visitors of an MS day care centre in Austria (Pilissy, 2017)

These users finally tested an iToilet prototype and confirmed the usefulness (Figure 4) of the individual physical support (Fazekas, 2019).

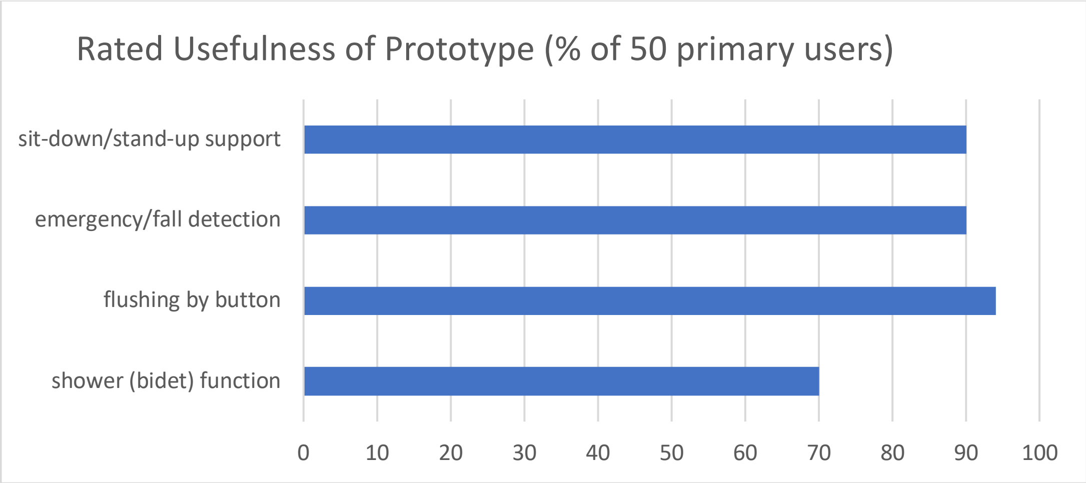

Figure 4. Total usefulness ratings for main selected functions by 50 primary users of the final iToilet prototype in Hungary (rehabilitation clinic) and Austria (MS day care centre). Opinions on bidet function in Austria were mixed while highly appreciated in Hungary.

In the current T4ME2 project, primary and secondary users in several European countries were asked to rate the many difficulties they are facing with the existing toilet infrastructure when outside the home, leading to a high amount of people stating that the lack of appropriate toilets keeps them from visiting public spaces and thus limiting them in their social activities (Figure 5).

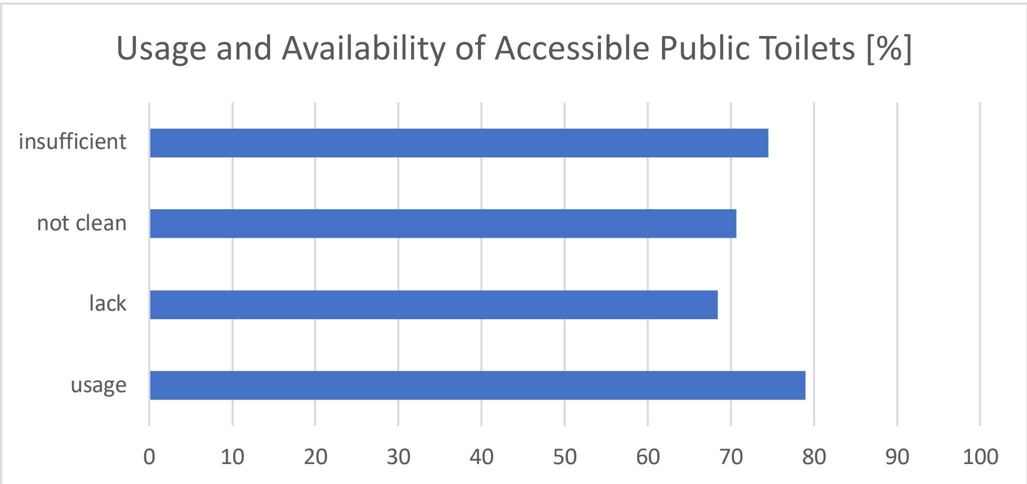

Figure 5. The percentage of usage and suitedness of accessible public toilets from 154 answers in an online poll in Austria, Belgium and the Netherlands (T4ME2, 2022), (Verburgt, 2021)

Detailed in-depth interviews then were performed with 61 primary users to learn more about their needs and opinions on semi-public toilets and the usefulness of functions (Figure 6).

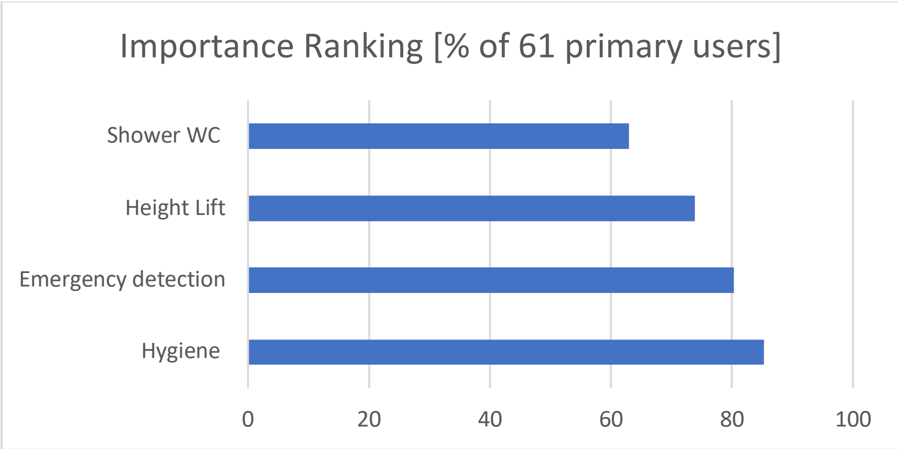

Figure 6. Importance ranking of functions from 61 interviews with primary users (Verburgt, 2021)

Many comments were also received on missing items in most toilet rooms, like adjustable mirrors, wash basins and wastebaskets, showing how little the usual barrier-free toilets fit the needs.

Reflection on Key Aspects

Smart adaptability

The variety of users in the semi-public area with their individual requirements calls for provisions in adapting the system to the preferences and needs of the users as much as possible for each current user instead of just one before installation.

Thus, the system should comprise means to get information about the users, their behaviour, and to estimate their needs. Communication between the system components should allow adding further optional features in a modular way making the system open for future enhancements also by third parties.

A flexible concept should also allow composing different solutions to fit market needs, especially also cost-related aspects.

Tests with a functional prototype

With the T4ME2 prototype 1 (PT1) we set out to demonstrate to users the different possibilities under supervision by researchers. With this we also wanted to react to the widespread lack of awareness about already existing technology. This prototype was a mobile chair-like construction (similar to those in Figure 1) to ease setup and testing which nevertheless provided new functional abilities, especially independent height and tilt adjustment, but still lacked a nice design (like cover). A smart 3D sensor (Lumetzberger, 2021) for detecting presence, position and body size of users allows to detect falls and general emergency situations like extended presence and completes the T4ME2 physical support by safety measures. The PT1 prototype represented all basically envisaged features.

Complexity and feeling of control and trust

Providing many ways of adaptation also brings the need to offer appropriate means of control. The classic way to add a dedicated button for every function quickly leads to unmanageable complexity of the user interface for many users, especially older users who are unfamiliar with modern technological concepts, discouraging them from touching the controls. Some users prefer a “one button per function” fully manual interface over too much automatism, on the other hand, automated reactions of the system relieve the user from complexity and provide more comfort.

At the beginning of the PT1 tests, many users expressed concerns about unintentionally pressing buttons because they initially were scared by the technical appearance of the unfamiliar technology. Many users expressed fear of losing control because they doubted to be fast enough to stop unwanted movement when needed and therefore being moved to positions where they might lose contact of their feet with the floor, causing instability. But on the other hand, we also received suggestions that sensors could care automatically for individually appropriate positions. Later all users learned to control positions of the toilet quite well.

To feel safe during the use of the support system, the user has to develop trust in the underlying algorithms and experience and understand sufficiently the behaviour and reactions of the system. This definitely is a challenge given the wide range of user requirements which requires compromises.

As a major consequence in order not to scare some (mostly first-time) users, it was decided to avoid any direct user noticeable automation and complexity and use smart algorithms only in the background e.g. for pre-setting the stand-up and sitting positions which then can be intentionally activated with simple and clear commands – by those users who already got familiar with how to use it.

The PT1 test also underlined the benefit of physical prototypes for research towards new features not yet available in the market with users having hands-on experience, instead of only asking theoretical questions.

Designing functional complexity and intentional feature unlocking

During a co-design exercise with users, the design and number of buttons for the remote control were worked out (Figure 7), resulting in a layout with 8 buttons in total.

There are separate buttons for changing height and tilt. The users concluded that this would be the best compromise between too many buttons and missing options. Every button press is confirmed by the LED on top lighting up and a beep if the command is accepted by the system.

It was decided that the default state of the system should be passive like normal accessible toilets. In this state, only the FLUSH and SOS functions should be available meaning no accidental activation of movement can occur.

To unlock the movement and shower functions, an intentional signal by the user is required showing that s/he wants to make use of and is aware of the functions.

As there are no dedicated buttons for this, the activation option on the hand control is implemented as a long press on the STOP button. A beep signal confirms the activation, and then the user manually may make use of all functionality.

Additional activation options are available when the user presents preferences to the system, either by using an RFID tag or a smartphone app. The activation can comprise just the unlocking, similar to using the long press of the STOP button or also communicate preferences for the positions for the sit-down, stand-up and sitting by pre-stored values.

In the case of values given by the user for the main use positions, the movement buttons for the height also offer to go to the sitting and stand-up positions with just a short button click instead of having to press the button until the required position is reached (similar to windows in cars).

Figure 7. Prototype of the hand control (left) based on findings from co-design activities carried out in 3 European countries (middle and right)

Another option provided by the 3D sensor of the system (which detects falls and emergencies) is to have the system estimate from a user's body size (and wheelchair use) the best positions without the need to use a tag or smartphone. After activation by the long press of the STOP button, the short click to go to the estimated positions is also available.

Of course, in any activation state, the STOP button always will stop any movement, and the usual manual adjustment of positions is always possible.

After a user has left, the system always returns to the passive state and the default position. Hence, every newly entering user finds the toilet in the usual position like every regular accessible toilet.

Hygiene and cleaning

From all research results, we see that users and stakeholders would strongly welcome solutions to keep the toilet – especially the seat - clean and technologies to support cleaning services. Possible solutions to keep toilets as clean as possible for all users range from the use of special coatings or seat material, also with antibacterial effect, to self-cleaning seats or disinfection by sprays or UV-C light after every user.

For our system concept, we decided to foresee a combination of special coating, UV-C disinfection (Jaglarz, 2020), monitoring of air quality (Orza, 2021) and estimation of usage frequency.

Many users also prefer to use a bidet shower function for their personal hygiene after use of the toilet over toilet paper because they find it difficult to reach back for cleaning or to fetch the toilet paper, others do not like it. For reasons of costs we decided to implement a shower seat.

Ethics

Our work is based on the strong involvement of often vulnerable users (Mayer and Panek, 2017) in the taboo area of going to the toilet, which makes strict compliance with ethical guidelines (Dantas, 2020), (Höllebrand and Oppenauer, 2020) and the establishment of a correspondingly well-founded interdisciplinary work (Zagler,

2008) indispensable. In the T4ME2 project, we established an ethics working group and advisory panel. In the iToilet project, we actively used tools such as the MEESTAR instrument (Manzeschke, 2015), which has proven to be very beneficial (Panek and Mayer, 2018).

Discussion of Differences between Home and Semi-public Environment

Looking at the user feedback in our projects (Fazekas, 2019), (Güldenpfennig, 2019), (Verburgt, 2021) we can conclude that the base idea of physical support is seen as helpful by a huge majority if the technology behind it is well explained. Users are even willing to use advanced functions like automatic position changes provided the user interface is straightforward, and the system is felt to be reliable.

In the example of the independent tilt function, it can be seen that unfamiliar concepts often are first not considered helpful and consequently not tried out. Once the users experience the different functions, they get interested in trying out different settings and quickly adopt strategies on how they could make the best use for themselves – but also start to imagine how useful it could be for others.

In the home environment, the so-found ideal operating principle can be easily implemented for every user. Special requirements of e.g. wheelchair users or users with low strength in the lower limbs can be taken into consideration and individual needs on the user interface can be fulfilled. Training can be individually tailored. This is similar in institutional settings.

If we go to the semi-public area we not only get an even broader potential user range but a new problem because of the to-be expected first-time users without training. The anxiety to use unknown functions and “machinery” which is looking complex here must not be underestimated, as seen during the PT1 tests.

The easy conclusion which might be drawn is to care for a nice non-technical design and limit the functions to only a few manually operated height change options like offered by simple commercial devices for home use, which is not suitable for people with different body sizes and properties. Some people not able to continuously operate manual buttons for the time needed to move the seat up could be prevented from making comfortable use, some would simply expect easy ways of moving to the main use positions fitting their needs.

This means that in one device, we would need a very simple solution for some, especially novice users, without visible complexity and scaring autonomous behaviour, and options for advanced functions without an extra complex-looking interface for more experienced users.

During business-related work with stakeholders, it became quite clear that costs also play an essential role in the adoption of smart toilets as usually only the mandatory investments into accessible semi-public toilets are taken if no clear return on investment (ROI) can be shown by offering advanced versions.

Conclusions and Outlook

The results in the iToilet and T4ME2 projects clearly show how helpful physical support by technology on the toilet can be for many disabled or older adults and that, in general, potential users and stakeholders are open to the idea, but at the same time, how demanding the task of developing such a system gets compared to solutions for home use. The most plausible approach seems to combine modified existing components of different manufacturers together with the required new developments for smart integration.

The adaptability to the broad user range requires many different, partly contradicting functions that cannot be active altogether at any time for every user. By involving users in the test of a first prototype and co-design activities, we came up with a concept which allows providing non-complex passive use to novice users while advanced users can choose to make use of additional functionality and provide preferences.

Figure 8. The final T4ME2 prototype 2 (PT2) with some of its main components: A wall-mounted ICT-enhanced motorised lift toilet (with shower seat add-on and built-in air quality sensor), an 8-buttons hand control, RFID tags (e.g. for recalling pre-stored individual settings) and a smart and privacy-aware 3D sensor for safety and presence detection. See (T4ME2 virtual room, 2022) for a clickable online demonstration of the PT2 and the whole toilet room

In the current T4ME2 project the final prototypes (Figure 8) implementing the concepts presented above will soon be delivered to three test sites for the final real-life user trials. We expect to get rich results on how the prototypes prove in practice. From this, our business partners will develop their exploitation strategy, which could lead to better accessible toilets in the semi-public area in the future.

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