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Development of an integrated staircase lift for home access

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Abstract

Purpose: Stairways into buildings present a significant environmental barrier for those with mobility impairments. A number of home access solutions that allow users to safely enter and exit the home exist; however, these all have some limitations. The purpose of this work was to develop a novel, inclusive home access solution that integrates a staircase and a lift into one device.

Method: We developed an integrated staircase lift following a structured protocol with stakeholders providing feedback at various stages in the design process, consistent with rehabilitation engineering design methods.

Results: A novel home access device was developed. The integrated staircase-lift has the following features: inclusivity, by a design that provides an option for either use of stairs or a lift; constant availability, with a lift platform always ready for use on either level; and potential aesthetic advantages when integrating the device into an existing home. The potential also exists for emergency descent during a power outage, and self-powered versions.

Conclusions: By engaging stakeholders in a user-centred design process, we were able to gain insight into the limitations of existing home access solutions and get specific feedback on our lift concept. This information strengthened the development of a novel home access device.

Keywords

Home access, accessibility, universal design, lift, independent living, user-centred design

Introduction

Stairways into buildings have been reported amongst the most challenging environmental barriers for users of wheeled mobility devices and those with mobility limitations associated with ageing.[1,2] The significance of this problem should not be underestimated. Reporting on findings from the National Health Interview Survey and the Census Bureau's Survey of Income and Program Participation, Maisel et al. note that approximately 1.7 to 2.3 million people in the United States (US) use wheeled mobility devices and an additional 6.1 million individuals use other devices, such as canes, crutches, or walkers. Quoting statistics from the National Center for Health Statistics 2006, Maisel et al. also note that in the US, 11.5 million people aged 65 and older reported difficulty climbing 10 steps without resting.[3]

With estimates of home inaccessibility as high as 90% in the US,[3] home access presents a significant barrier to people with mobility impairments and those wanting to age in place.[4–7] Traditional solutions to addressing home inaccessibility have typically involved either moving to alternate housing or modifying the home to remove accessibility barriers.[3] The complex challenges associated with a move and the failure of many to adequately modify their homes[8] have serious implications for people with mobility limitations. Inaccessible housing has been associated with premature institutionalization, increased care costs,

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deteriorating health and well-being, dislocated family relations, and recourse to higher dependency housing.[3,9–11]

Home access solutions aim to address the architectural barrier that stairs present and allow users to safely enter and exit the home while maintaining as much independence as possible.[8] Existing home access solutions range from relatively inexpensive handrails and ramps to more costly elevators and lifts. Lifts can be categorized into three broad groups: 1) vertical platform lifts—designed to transport the user vertically between two or three floor levels; 2) inclined platform lifts (also referred to as wheelchair platform lifts)—designed to transport the user in his or her own wheelchair between levels on an incline such as along a stairway; and 3) stair glides (also referred to as stair lifts, stair-chair lifts, and stair climbers)—designed to transport the user on an integrated seat between floor levels while traveling on an incline such as along a stairway.[12] While a few new solutions have been developed in recent years,[13–15] the uptake of these solutions is limited to specific niche applications.

Studies looking at the benefits and limitations of 'traditional' home access solutions point to several drawbacks with these solutions. While ramps typically offer a lower cost access solution, their large footprint and impact on home aesthetics limits the locations in which they can be used and reduces their desirability for many.[16,17] Safety concerns such as the grade of the ramp, challenges negotiating tight ramp corners, and the effects of weather on ramp slipperiness have also been reported.[17–19] Elevators have been identified as effective solutions in terms of speed, capacity, rise and usability; however, the need for adequate space, and the high costs associated with their purchase, installation, and maintenance are significant drawbacks, thus limiting their use in typical home settings.[12] Platform lifts and stair glides remain the 'devices of choice' for small elevation changes[12] in existing homes; however, these also have their limitations. For platform lifts, limitations relating to use, size, speed, capacity, and rise have been identified.[12] For stair glides, the need to transfer on and off the chair (often at the top of the stairs—one of the most dangerous places in a house) poses risks for those with transfer, balance or visual limitations,[20] and the fact that they do not provide access for wheeled mobility devices limits their usability for many.[12] In addition, anecdotally, stair glides do not provide quality access, marginalizing individual dignity with their slow, cumbersome use.

Two other significant drawbacks inherent with existing home access solutions are that they do not embrace inclusive design principles (i.e. they have not been designed to include the needs of the widest number of consumers[21]) and they appear to many as obvious symbols of disability. These have been reported to negatively impact the self-identity of residents and their relationship with neighbours, as well as make residents feel less secure, even vulnerable.[22,23] It has been suggested that these factors may compromise the functionality and expected benefits of home access solutions.[22]

This work aimed to address some of the drawbacks of existing home access solutions through the development of a new solution—the ARISE integrated staircase lift. This novel design aims to: address inclusivity by providing a staircase and lift in the same access location and footprint; encourage stair use whenever possible (e.g. for exercise), as well as offer the safety and convenience of a lift when necessary (e.g. when the person is encumbered or using a wheelchair); and provide repeatable emergency descent from a house in times of power outages. The device allows for use of stairs or the lift to access the same entrance whether walking, using a wheelchair, using a walker or pushing a stroller.

This paper explores the technical development of the ARISE home access solution as well as the experience of user involvement in the design process.

Methodology

The development of the ARISE was based on a structured, user-driven design process that involved obtaining feedback from stakeholders during the design cycle, and using these results to inform subsequent stages of development. The methods used to design the device and obtain stakeholder feedback are outlined below.

Design

The design and development of the ARISE were conducted under the structure of the International Organization for Standardization (ISO) 9001 Quality Management System, in the context of rehabilitation engineering design that includes user feedback at various stages. The ISO is an internationally recognized organization that provides guidance and tools for those who want to ensure that their products and services consistently meet customers' requirements, and that quality is consistently improved.[24] The Quality Management System provides a systematic framework for product development and evaluation that includes the development of design requirements, a risk management process (including hazard analysis), as well as verification and validation (terms defined below).

A schematic of the iterative process used for this project is presented in Figure 1. The first stage of the design process involved developing preliminary design requirements. Design requirements are a set of

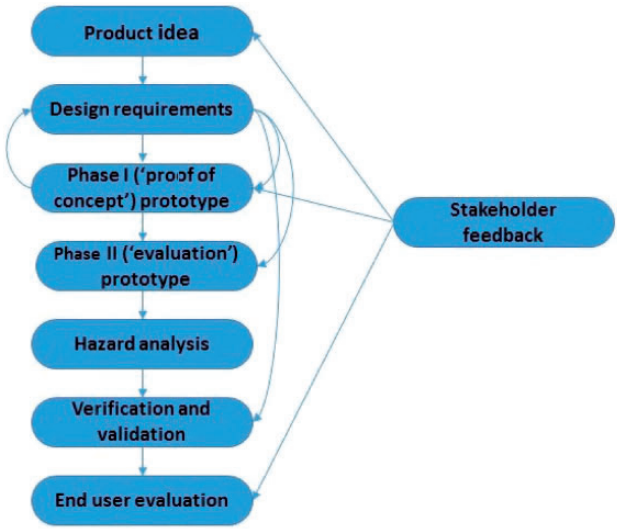

Figure 1. Iterative design process used for the development of the ARISE.

unambiguous and verifiable descriptions of desired product attributes. Design requirements are fundamental to the product development process and serve as terms of reference for all subsequent product development and evaluation phases. Using these requirements, a Phase I ('proof of concept') prototype was constructed to demonstrate the basic functionality of the ARISE design. Next, stakeholder perspectives were explored through a series of interviews with occupational therapists (OTs) and two focus groups with end users. (Note: As the ARISE development was still in the early concept stage, OTs (rather than end users) were first interviewed to provide a broad perspective of home access needs of a number of disability groups and to help narrow potential end user groups. OTs working in community care were chosen as stakeholders as in their practice they assist clients by providing recommendations for home access solutions based on their unique needs.) Stakeholder perspectives were used to revise design requirements, which were then used as a framework for the design and construction of a Phase II ('evaluation') prototype. After verifying the Phase II prototype (i.e. confirming that the product met the design requirements and fulfilled its intended purpose), a hazard analysis and risk assessment was performed. A hazard analysis is a detailed examination of the device from the user and patient perspective that aims to detect potential safety issues so they can be corrected before the device is used. The risk analysis determines the probability and severity of the potential hazard. The final stage of this work involved end users validating the design (i.e. confirming it met the needs of those who would use it) through the evaluation of a full-scale working model of the ARISE against other commercially available home access solutions.

Stakeholder feedback

Stakeholder feedback involved both interviews with OTs and focus groups with wheelchair users. The protocols for both of these studies were approved by our ethics review board. Details of the methods and data analysis used to obtain stakeholder feedback are described below.

Sample. Purposive sampling was employed to recruit eight OTs with experience practicing in community care for the interviews, and eight wheelchair users for the focus groups. The focus group participants represented a heterogeneous population, including male and female participants with different mobility limitations and differing prior experience with home access solutions.

Methods. The protocol for the OT interviews involved presenting digital renderings of the ARISE concept, then using a semi-structured interview script to guide discussions. The script included questions about past experiences with existing home access solutions, factors influencing the recommendation process, as well as questions aimed at soliciting feedback on the ARISE concept (general impressions of the design, benefits, limitations, etc.). The protocol and interview script were pilot tested with one OT to ensure that questions were appropriate and reflective of practice. Minor modifications to wording and question order were made based on the pilot feedback.

The focus group protocol developed for the wheelchair users aimed to gather end user perspectives on existing home access solutions, as well as the ARISE design. First, participants were shown images of existing home access solutions (platform lift, stair glide, ramps, etc.) to stimulate discussion about these products. Second, participants were shown a digital animation of an externally powered (i.e. automated) version of the ARISE in use, as well as short videos of self-powered versions of the lift. A semi-structured focus group script was used to guide discussion. The script included questions about the benefits and limitations of existing solutions, as well as questions focused on obtaining general feedback on the ARISE concepts. Prior to data collection, the script was piloted in a focus group with OT students and research team members. Minor changes were made based on their feedback (e.g. having the ARISE animation run in a continuous loop while the lift's features are being described).

Prior to all data collection sessions, participants were required to sign informed consent forms.

Sessions were 60–90 minutes long and were audio-recorded and transcribed verbatim. Use of the interview script was dynamic to allow for discussion of emerging themes in subsequent interviews.[25]

Analysis. Transcribed interviews were analyzed using the phenomenological method outlined by Colaizzi.[26] First the transcripts were read by two researchers to acquire an overall sense of the interviews. Researchers then independently extracted significant statements from the data in the form of phrases that captured the meaning of the participants' responses. The phrases were then classified into broader categories. Finally, the researchers used data display (i.e. charts and concept maps) to cluster the categories into meaningful themes, and created a description of these themes. These themes were presented to the rest of the research team for further discussion and refinement. Member checking was used to verify the accuracy of the initial findings. This step was taken to seek clarification from participants and help ensure researchers accurately represented participant perspectives while also verifying the interpretation process.[27] Member checking was performed through a 10- to 15-minute phone interview (with all participants) once initial findings were identified.

Focus group data were also analyzed using a phenomenological approach.[26] The data were analyzed via the following three steps: acquire a sense of the transcript (by listening to the recordings of the sessions and re-reading the transcripts multiple times), extract significant statements, and formulate meanings.[28] Significant statements that had the same or similar meanings were then clustered to form categories. A data display in the form of a concept map was used to arrange the categories into meaningful theme clusters. Member checking (with all participants) via phone or email was used to verify the accuracy of the initial findings.[27]

Results

The following section outlines the results from all stages of this work, including the development of the proof-of-concept prototype, findings from the stakeholder feedback (interviews with OTs and focus groups with wheelchair users), and a description of how stakeholder feedback was used to develop the final Phase II evaluation prototype.

Phase I ('proof-of-concept') prototype

At the outset of the project, preliminary design requirements were developed based on a concept envisioned by the principal investigator (a wheelchair user) and supported by anecdotal feedback from other wheelchair users. Notable requirements for the concept are listed in Table 1.

Table 1. Key design requirements used in the development of the ARISE.

Key design requirements
Inclusive design usable by people with a range of mobility impairments, including those with wheelchairs and walkers
Is 'always available', i.e. doesn't need to be called from another floor
Provides the option for users to use stairs
Stair tread rise to run ratio consistent with current building codes
Form factor that allows aesthetic integration with North American bungalow homes
Potential for a self-powered version (i.e. no external power required)
Usable for emergency descent in absence of power

Figure 2. First full-scale prototype of the ARISE. It is inherently a conventional staircase but each end of the staircase also can operate as a platform lift.

Based on these requirements, a basic proof-of-concept prototype was built to demonstrate the concept feasibility. Figure 2 depicts our first full-scale Phase I prototype, designed to elevate approximately 0.9 m (five stairs). This design has two major home access characteristics: 1) it is inherently a conventional staircase; and 2) each end of the staircase can operate as a platform lift. A person (e.g. in a wheelchair or otherwise) can enter either the top or bottom staircase platform, thus there is never a need to 'call' or wait for the platform. Each platform is similar in size to a conventional vertical platform lift, and large enough to accommodate two people or a wheelchair. Each platform is hinged to the frame of the staircase in such a manner that a levered platform lift is realized, operationally analogous to a 'see-saw'. The frame of the stairs, handrails, and vertical platform posts form a parallelogram linkage (see Figure 3). The entire symmetrical structure pivots around two horizontal axes placed at the centre of the stairs and handrails (red arrows in Figure 3). The parallelogram linkage allows the user to quickly raise or lower to a different level while still maintaining each of the platforms in a horizontal orientation at all times.

The ARISE design also maintains a normal staircase for use by others when the lift is not in use, regardless of which platform is in the upper position. To prevent falls, especially by older adults, the literature recommends that stair-riser heights and tread lengths conform to specific asymmetrical geometries (e.g. a rise-to-run ratio of ~7:11).[29,30] In order to maintain proper stair geometry when the ARISE swaps positions, the ARISE uses a pivoting mechanism that links each stair riser to another parallel linkage (blue arrow in Figure 3). We were able to validate the feasibility of this stair pivot mechanism, demonstrating the ability to maintain stair treads in a horizontal position for normal stair use, while still preserving the appropriate rise-to-run ratio when either end of the platform is raised into its end position. In addition, we were able to confirm that this dynamic structure still provides a conventional stiff feel when walking up or down the stairs. This stair design has the added benefit of providing adjustability for various heights of entry levels, as the entire structure can accommodate changes in elevation of several inches by slightly altering the 7:11 ratio. Changes beyond several inches would simply require another step to be added to the staircase.

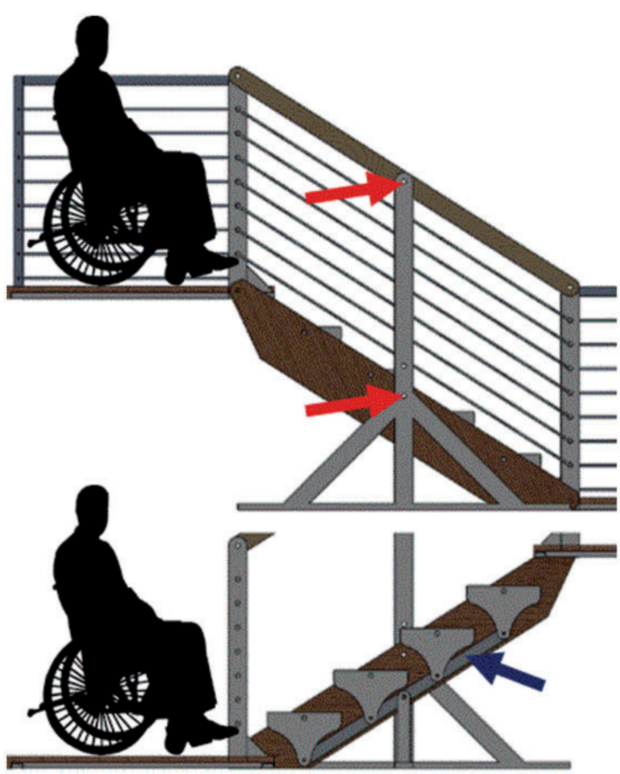

Figure 3. The ARISE design. The entire structure moves about two pivot axes (red arrows), providing the pivoting lift action. The bottom cutaway model shows the internal linkage (blue arrow) of the staircase treads.

To address potential home design integration, a number of bungalow-style houses with five to six steps were identified locally (although heights greater than six stairs may also be appropriate for this design). An Architectural Sciences student modeled several alternatives for aesthetically and functionally integrating the ARISE into these homes (see Figure 4 for a sample rendering of an early ARISE configuration).

To simplify installation and removal, a concept for a removable porch landing that could be constructed over an existing staircase for installation of the ARISE was developed. For a home entrance elevation served by five stairs, the ARISE requires a landing (e.g. front porch) of about 4 m in length. The landing size grows only about 30 cm per additional stair; e.g. for 10 stairs, the landing is approximately 5.4 m long. This footprint is much smaller than a comparable ramp. For example, a 1:12 ramp serving a home of five stairs has a footprint of 16 m and an equivalent ramp serving a home of 10 stairs has a footprint of almost 32 m. (If a gentler, 1:16 rise-to-run ratio is used, the ramp footprints increase to 19 m and 38 m for five and 10 stair heights, respectively).

The Phase I prototype was tested with loads up to 140 kg and it was demonstrated that the platforms could easily be moved the entire vertical distance in a very smooth and quick manner (2–3 seconds from bottom to top). When in a balanced condition (e.g. a person on one side and an equivalent weight on the opposite platform), very little effort was required to push or pull a platform and manually move the lift from one position to the other (i.e. as with a balanced see-saw, only the force required to overcome frictional forces in the pivots is required). It is possible that low- or self-powered versions of the ARISE design may be feasible by counterbalancing the lift in some fashion. For example, a counterbalancing weight could shoulder the load of one side of the ARISE, providing the bulk of the lifting force necessary to raise the occupant, with only a little effort from the occupant necessary to pull himself or herself and the lift from one position to

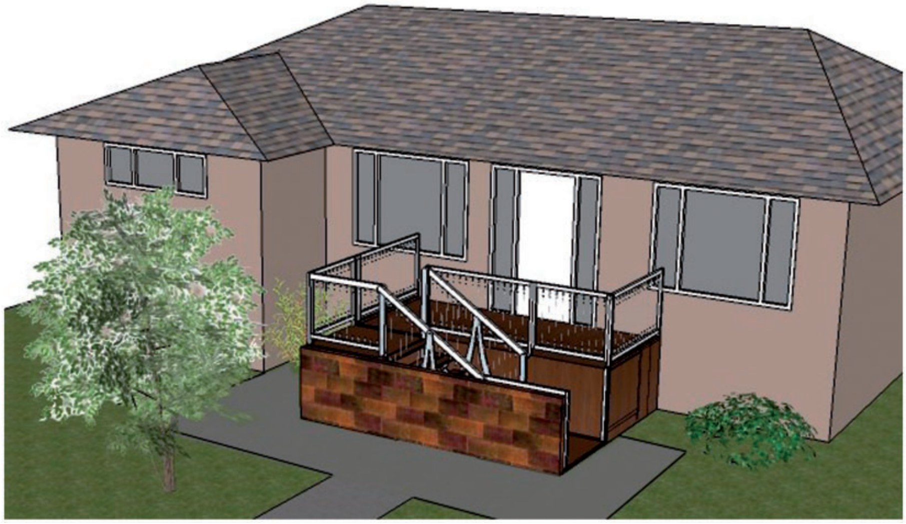

Figure 4. Early rendering of the ARISE integrated into the front porch of a bungalow home.

another. We tested this concept using gas springs as a counterweight force, demonstrating that not only did gas springs greatly reduce the forces required to raise a user, the damping they provided while lowering the user resulted in a smoother, gentler ride and also provided a means of powerless emergency egress.

While counterbalancing (with weights or gas springs) was shown to reduce the lift forces, a drive mechanism for the ARISE was still required. Prototype self-powered drive mechanisms were developed, including a simple hand crank drive, and a lever drive attached to a chain and sprockets. Using these drive mechanisms, users were able to raise themselves 0.9 m in approximately 12 seconds and 14 seconds, respectively. Later, a scaled prototype of an improved lever system was developed. This lever mechanism incorporated a gearing system with one-way bearings that translated both fore-aft lever motions into a unidirectional lifting or lowering action. It is estimated that such a system would allow a user to rise about 1 m with four movements of the lever, taking approximately 7 seconds (approximately the same time required for a conventional platform lift to travel this distance).

Feedback from OTs

Several key factors emerged from an analysis of the interviews. OTs, without exception, identified cost as the most commonly cited concern influencing an end users' choice of home access solutions. In order for the ARISE to be a viable solution it was noted that the cost must be within a manageable price range or the device must become eligible for funding. Safety was also brought up as an important factor. For the ARISE, OTs noted the importance of including a full range of safety features such as gates, railings, emergency stop, etc.

The importance of aesthetics and the access solution 'fitting' the house (i.e. the height of the entry, the footprint, landscaping issues) were also brought up as important. Apart from end users wanting the front of their home to look nice, they are also looking for more subtle and unobtrusive solutions that don't create the stigma that is often associated with disability-related products. OTs noted that solutions that 'advertise' disability can make end users feel vulnerable, as they perceive themselves as a potential target for criminal activity. One OT commented that the ARISE design doesn't '*scream out disability*', while another stated that it looked '*more normalizing*'. The fact that the ARISE embraces inclusive design principles and provides solutions for people with a range of disabilities was also well received.

The end users' condition and prognosis (i.e. relating to both physical and cognitive abilities), as well as the potential presence of a caregiver, were stated as important factors that influenced choice of home access solution. OTs suggested that the ARISE would be particularly well suited for people with energy issues (e.g. those with multiple sclerosis, chronic fatigue, and mobility impairments associated with ageing), or for people whose mobility may vary or decline over time (e.g. walking now but may need a wheelchair down the road). Ease of installation and having the ability to remove the access solution if the house is sold were also noted as important considerations.

Finally, the possibility that the ARISE could be self-powered, or at least operational for emergency egress, was considered to be a benefit as it was noted that people like something that doesn't necessarily rely on an external power source that could occasionally be out of service.

Feedback from end users (wheelchair users)

End users confirmed that home access solutions are an essential component for providing the opportunity to engage in activities outside the home, and that similarly, ineffective home access solutions can create barriers to participation, including limiting activities related to self-care (e.g. bringing groceries into the home). When comparing the benefits and limitations of existing home access solutions, important characteristics identified included: cost, safety, feelings of security, durability (especially for outdoors), dependability, usability, speed, noise, and maintenance.

As in the interviews with OTs, cost was identified as an important factor that often determined choice of one home access solution over another. The importance of factoring in repair and maintenance costs was also discussed, with some participants citing stair-lifts and elevators as examples of solutions with high servicing costs. When participants were asked if they would consider using the ARISE, there was an overall preference for the manual self-powered ARISE version, in part due to perceived lower maintenance needs.

The importance of the assistive technology-human fit was also discussed, with a number of users highlighting the value of designing a device that can accommodate a diverse array of end-user needs. There were some concerns that the ARISE may benefit only individuals with a certain degree of functional mobility. In particular, it was noted that a self-powered version of the ARISE would not fit all end users as some would not have the strength to operate it. On the other hand, when asked if they would consider using the ARISE, most participants preferred the self-powered version of the ARISE because of the sense of control and independence it could provide to the end user.

Participants also noted that 'user space' in home access solutions, such as floor area inside elevators, is important, noting that there should be enough room to turn around or allow a caregiver to accompany a person in a wheelchair. When participants were shown an animation of the Phase I ARISE design, where users were required to pivot 90 degrees toward the exit upon entering the platform, several participants stated that this small radius turn would be challenging for many. Several participants noted that straight in/straight out access was preferred.

The importance of the aesthetics of home access solutions was also discussed. Participants noted that solutions that were discreet in appearance and could be integrated into the home were viewed more favorably. As in the OT interviews, participants expressed that home access solutions that do not advertise disability to the public were considered more desirable as they felt visible solutions could make them targets for criminal activity. Interestingly, although the ARISE was considered to be aesthetically appealing by some, others suggested that making an aesthetically appealing home access solution is difficult or impossible to do, noting that most are bulky and don't 'blend in'. Some participants questioned the versatility of the ARISE and wondered about its ability to fit different types of homes.

Phase II ('evaluation') prototype

All stakeholder feedback was carefully reviewed by the design team and decisions about which design modifications to pursue were made by the team based on practicality, relevance to project goals, as well as budgetary and time constraints. Some feedback led to significant design changes that were incorporated into the design of the Phase II prototype. For example, the entry/exit path for the lift was changed to straight through access (rather than the 90-degree turn of the original concept). Also, based on the stakeholder feedback of the importance of the appearance of the solution, additional aesthetic details were added to the design. These included using composite decking planks for the stair treads/platforms and incorporating planters in front of the ARISE to make the solution look less 'clinical'.

Some design decisions were made that did not directly align with user feedback. For example, keeping the solution low cost was brought up repeatedly by stakeholders and its importance was well recognized by the team. However, at times keeping the solution low cost conflicted with other priorities (e.g. developing an inclusive design). In our case, because we wanted to develop a prototype that could be evaluated by many, developing the most inclusive solution was prioritized. For example, using manual gates to control entry and exit would have been more cost effective than the automatic gates that were used; however, this may have affected the range of participants able to easily use the prototype. It was recognized that a lower cost version of the ARISE concept with manual gates could be developed in a future version if the overall lift concept was well supported in the subsequent evaluation (an option that can be found in many home lifts on the market).

The feedback related to the development of an automated or self-powered lift was also considered carefully. Some feedback stated that a manually operated lift would be more reliable, provide users with increased independence, and be lower cost. At the same time, it was noted that many potential users would not have the upper extremity function to use a self-powered lift. Once again, we decided that an inclusive design that could be evaluated by a wide range of end users should be prioritized. As a result, the Phase II prototype was developed as an externally powered version of the ARISE. (It should be noted that, as the importance of maintaining emergency egress in the case of a power failure was confirmed by stakeholders, this remained a requirement for the evaluation prototype.) The rest of this paper discusses the more conventional externally powered ARISE; however, further work on self-powered options is planned, in particular for possible use as a low-cost alternative both in North America and potentially in low-resource settings.[31]

For the automated ARISE design, a number of externally powered drive mechanisms were considered. The final design selected was based on a bi-directional hydraulic actuator that pulled either end down (thus lifting the other platform), and that could be mounted beneath the stairs. A block and tackle pulley mechanism was incorporated into the design to multiply the lift distance by 3 (see Figure 5), thus providing a 0.9 m lift while still keeping the drive mechanism contained in the limited space under the stairs. To create a smoother ride for the user, control algorithms to slow the lift at the beginning and end of the lift cycle were developed. The system was powered by a 12 V battery (trickle-charged through an AC line) that also served as an emergency backup system in the event of a power failure. A push-button switch mounted on the side panel of the platform was put in place for the user to control the lift. As a safety feature, the push button operated as a 'deadman's switch', i.e. the lift stopped the moment the switch was released.

A number of safety systems were put in place to ensure safe operation of the ARISE during the evaluation. A total of four gates were included in the ARISE design (one exit gate and one entry gate for each platform). Gates consisted of pivoting bars (anchored to the platform frame uprights), driven by small micro-controller-activated motors. The micro-controller was programmed to sequence the opening and closing of gates with the lift operation: i.e. closing the 'entry' gates when the operation button was pressed and opening the 'exit' gates when the next level was reached. As an additional safety feature, the ARISE was designed to operate only when all of the gates were closed. Other safety features included an external 'emergency stop' switch (a system over-ride held by the supervising researcher), rails on both sides of the stairs, and a vertical safety barrier that prevented a user's wheelchair rolling off the platform when it left the ground. This vertical safety barrier also had a secondary purpose, acting as a transition ramp to assist users getting over the lip to the ARISE platform when the platform was on the ground. As operation of the evaluation prototype was limited to the controlled setting of the lab, the team was able to bypass some safeties that would be required for safe operation in a public space. Regardless, further features that simply provided the 'perception of safety' and inspired user confidence were also included in the design: visual barriers under the lift platforms (e.g. rolling blinds that unfurled as a platform lifted—see red arrows in Figure 6) were installed to obscure the view of moving parts under the platform.

Prior to using the ARISE for the evaluation, the prototype was verified against design requirements, and underwent a detailed hazard analysis (see final Phase II prototype, Figure 6). Identified hazards were addressed and safe operating protocols were put in place. ARISE specifications (i.e. time to another level, platform size, and footprint) were recorded and tabulated against specifications from existing home access solutions)—see Table 2. The next stage of this work involved engaging end users to evaluate the ARISE

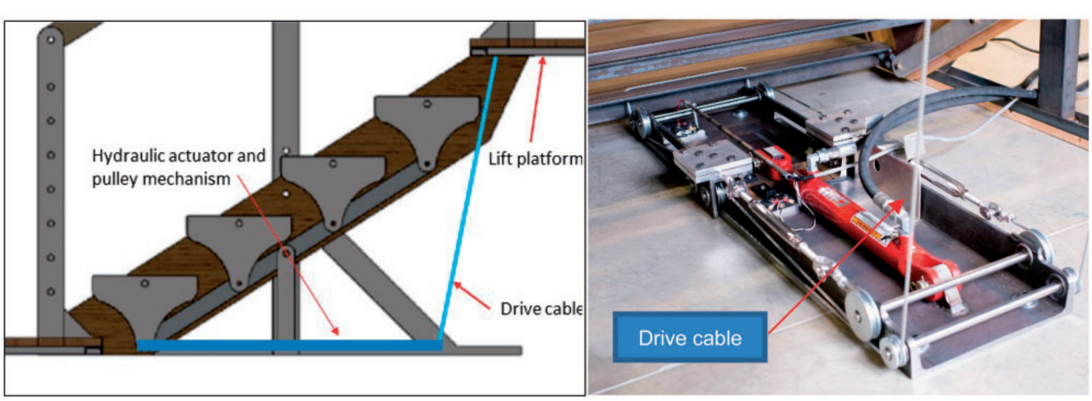

Figure 5. Drive mechanism for the ARISE: drawing showing location of drive mechanism and one of the drive cables (left), and photo of hydraulic actuator and block and tackle pulley mechanism (right).

Figure 6. Phase II ARISE prototype ready for evaluation with end users. The two platforms are shown both in the raised and lowered positions. The locations of the rolling blinds are indicated with red arrows.

Table 2. ARISE specifications compared with other home access solutions.

Home access solution	Approximate time to another level (seconds)[a]	Platform size (m)	Footprint (m^2)
ARISE	10	1.2 × 0.9	5.3
Savaria Platform lift (Savaria)	17	1.4 × 0.9	2.5
Stair Glide (Bruno Elite)	32	n/a	0.8 m width along length of stairs (stairs footprint = 2.6 m^2 including landing)
Ramp (1:12 rise to run ratio)	26	n/a	13.4

[a]Includes time to get on the lift and exit.

(i.e. validate the solution) and compare it with other solutions. Findings from this evaluation will be reported elsewhere.

Discussion

In order to address the limited innovation in home access solutions, we employed a user-centred design process to develop a novel home access device that integrated a staircase and vertical platform lift into one inclusive package. The ARISE is 'always available' (i.e. a user never has to 'call' a lift platform as there is always a platform waiting for the user on either level), provides an option for the user to use stairs or a lift, and is usable by people with a range of mobility impairments. This solution is also usable for emergency descent in the absence of power and has potential for low- or self-powered applications. This discussion section provides an overview of our outcomes, as well as some of the implications of our work, including issues relating to the speed of the device, the user-technology fit, and prospects for a self-powered system.

Through verification of the prototype and user feedback we were able to demonstrate that the ARISE has the potential to address some of the limitations of existing home access solutions. For example, stakeholders commented that the ARISE does not appear as a solution for a person with a disability, and it incorporates inclusive design principles. Further, the ARISE addresses one of the main drawbacks of ramps—i.e. their large footprint.[17] The ARISE footprint is only slightly larger than a conventional staircase, and much smaller than the footprint of a comparable ramp (while still preserving the use of stairs—see Figure 7).

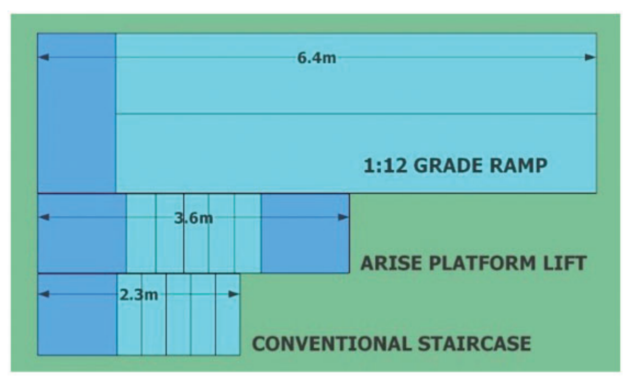

Figure 7. Footprint comparison for three home access solutions servicing a height of five stairs: a 1:12 grade ramp (with switchback), the ARISE platform lift, and a conventional staircase.

Frustration with speed of existing home access solutions (in particular elevators and platform lifts) has been noted both in the literature[12] and by stakeholders participating in this study. We were able to demonstrate that the ARISE is considerably faster than the solutions tested (a platform lift, a stair glide and a ramp). It should be noted that while speed of existing home access solutions is a frustration for some, speed is in many cases governed by regulation. For this research, the team intentionally set out to create a lift that was faster than current regulation allows in order to explore user perceptions of what is acceptable across a wider range of speeds. Regulatory changes may be required if the faster operational speed were to be incorporated in a commercial product. Regardless, even if the ARISE must be configured to an operational speed that conforms to current regulation, the overall efficiency of the ARISE may be an improvement over existing lifts and stair glides as both these solutions often times require the user to wait while the lift is called.

Another issue brought up by the stakeholders in our study was the importance of the technology being matched to the user. The literature supports these comments, noting that home access solutions should be matched to the individual's unique functional abilities, housing situation, personal preferences, family support, resources, and levels of independence and participation.[22,32] Providing flexible solutions that could be customizable to the individual may facilitate this matching process. Results from our study indicate that the ARISE appears to have the flexibility to be used by users with a range of mobility challenges. As it can be used as a set of stairs by those who are able (thus obtaining valuable exercise[32]) or as a lift (for those requiring assistance), the ARISE is well suited for users with changing conditions. In the longer term, this can prove to be an economical option for users whose condition may either improve (through rehabilitation) or deteriorate (with a progressive condition like multiple sclerosis) over time. Similarly, providing a self-powered version of the ARISE to those with the required upper extremity function to operate it would likely provide a lower-cost (and more reliable) alternative.

Indeed feedback from stakeholders supports further work on a self-powered version of the ARISE. The premise of the self-powered operation is based on the ability to counterbalance the lift. In many personal home access situations, the lift could be counterbalanced primarily for an individual and his or her own home. As the occupant would almost always use the same platform, the weight of the counterbalance (or force of the gas spring) would be appropriate for this specific user and his or her wheelchair. In most typical situations, the primary user would be able to operate the lift manually and independently with little or no externally supplied power. For scenarios where other people (e.g. visitors) would use the lift, and for the situation where the position of the primary lift platform and the typical occupant were mismatched, a relatively small geared motor could be used. Here, the motor could 'reset' the lift by slowly moving the un-balanced structure to the opposite position. Low- or self-powered versions of the ARISE could have many different use scenarios, including providing reliability during a power failure, fostering user independence, promoting environmental sustainability, and providing solutions in regions where power is not available. Details of applications in low-resource settings are described elsewhere.[31]

The design process used for the development of the ARISE prototype followed a structured protocol that involved stakeholders providing feedback during development, consistent with rehabilitation engineering design methods. Others have shown the benefits of incorporating potential end users in the design process.[33–35] While including the opinions of stakeholders has always been central to our development model, some of the difficult design decisions discussed in this paper highlight how this methodology can sometimes present challenges. Often feedback from stakeholders was easily supported with a straightforward change (e.g. alter the entry/exit path or include additional aesthetic details). But in some cases there were conflicts with user feedback and other design priorities, and/or conflicts relating to the needs of other potential users. We were faced with two major conflicts in this project: the decision about manual vs. automatic gates, and the decision about self- vs. externally powered lift actuation. Both decisions affected potential manufacturing cost and design inclusiveness. Due to the early stage of device development and original project goals, inclusiveness was pursued at the expense of cost and other considerations. In the end, we were able to create a device useful to a wide range of people with many different disabilities and needs. Thus, our subsequent evaluation can be larger in scope and inclusiveness, and will allow us to obtain more user feedback in the next phase of this work.

In spite of the challenges of a user-centred design process, we maintain that including the opinions of end users in the design process is critical to success. A review of novel home access solutions in the marketplace reveals that some of the issues brought up by stakeholders and considered during the design and development of the ARISE are also being considered by others. For example, a company with an integrated home access solution that functions as both a staircase and a lift[14] aims to address the importance of providing both a flexible and aesthetic solution. Similarly, a company that describes a low-profile home access solution aims to provide an inconspicuous solution that blends into a home,[13] while a company with a vacuum elevator discusses the benefits of a lower energy solution, including no-power descent.[15] While it is encouraging to see that some of the limitations of home access solutions that have been discussed in this paper are being considered by others, use of these innovative solutions is not widespread and it is evident that gaps still exist. Innovation in this area is limited, and the market is ripe for new solutions. Results from this work support further development in this area.

Conclusion

By engaging stakeholders in a user-centred design process, we were able to gain insight on limitations of existing home access solutions and get valuable feedback that strengthened the development of the new ARISE design. We were able to demonstrate that this solution has potential to address shortcomings of existing home access solutions and provide inclusive home access to a range of end users. Overall, stakeholders expressed enthusiasm for the ARISE. In particular, stakeholders noted advantages of the inclusive design, as well as potential benefits with the aesthetics of the solution. However, limitations were also noted. The complexity of the device was likely the most considerable challenge as users felt this would affect both cost and reliability of the solution. Engaging stakeholders in the design cycle proved to add value to the process and emphasized the need for continued feedback from end users through all stages of development.

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Conflict of interest

None declared.

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