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AN AIRCRAFT COMBINATION WHEELCHAIR SEAT SUITABLE FOR AIRCRAFT AISLES

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***Abstract*:** Air travel is very restricted for individuals with mobility limitations and there is a need for the design of improved accommodation for individuals in wheelchairs on an aircraft. The aim of this paper is to present an aircraft wheelchair design, referred to as the Aircraft Combination Wheelchair Seat (ACWS), that meets the requirements of the dimensions of the Airbus A321 aircraft aisles and facilitates aircraft mobility. This study focuses on the process of the design and the analysis undertaken. The universal design approach ensures the product can be used for more than one function, including, the ability to be fully integrated into the airline seat or the reverse, to be detached from the seat frame. Finite element analysis performed on both options concluded that the product was technically feasible.

Keywords: Wheelchair, aircraft, disabilities, accessibility, universal design.

Introduction

With 1.2 million people using wheelchairs in the UK (Papworth, 2016) it is important to consider the unique difficulties in completing certain common tasks. The focus area of this study are air flights, this is due to travelling being seen as a way to fulfil an individual’s need for independence (Turco,

1998) and promoting positive wellbeing, including improved health. In fact Pyke et al. (2016) and Smith & Diekmann (2017), amongst others, have demonstrated the wellbeing value of travelling for all individuals and that all forms of tourism contribute to and boost wellbeing. Chen et al. (2013) highlighted the positive connotation of tourism as being the opportunity to relax and recuperate. Other studies, such as Morgan et al. (2015), explored the links between wellbeing and social tourism opportunities for elderly people, noting that often it is the elderly that require mobility support in order to be able to travel and concluded that social tourism provides an opportunity for respite, escape and companionship for this group. Thus tourism positively impacts disadvantaged groups, which includes people with disabilities and health challenges and their carers, and also alleviates stress (McCabe, 2010; Morgan, 2015).

The desire for travel is the same for both individuals with or without disabilities (Yau, 2004), however, people with disabilities travel 33% less often than the general public (DCLG, 2014). This could be attributed to the fact that travelling by aircraft while in a wheelchair comes with a variety of constraints, barriers and challenges. The main being the passengers with disabilities' wheelchair is too large to fit down the narrow aisles and into the small bathroom. The lack of provision of a user friendly onboard bathroom in aircrafts for people with disabilities has been recognised in the literature (Chang, 2011, 2012) and thus often people with disabilities opt not to travel because the facilities and services are not adequate for their needs.

Although the airlines are legally required to deliver the passenger with both equipment and assistance (EC, 2007), what is provided is very basic and needs to be improved. In particular, the wheelchairs provided cannot fit into the small bathrooms on short-haul flights, as aircrafts are only required to have disabled accessible toilets on long-haul flights. When it comes to using the toilet facilities, passengers with disabilities are currently recommended by travel blogs to avoid using the bathroom through fasting, use of incontinence pads or catheterisation (Chaluent, 2014). This is to avoid the uncomfortable manual-handling and embarrassment that comes with using the bathroom as a wheelchair-user (Davies & Christie, 2017).

Thus the aim of this study was to design a wheelchair that is compact enough to be able to fit down the narrow aisles of an aircraft and also be able to be manoeuvred into the bathroom, allowing passengers to transfer themselves over onto the toilet without having to be manually lifted. The purpose of this study is to minimise wheelchair passengers' concerns when travelling by air, to allow them to keep their dignity while using the bathroom and increasing the number of wheelchair passengers travelling by aeroplanes. This study analyses a conceptual design and discusses the mechanisms of the design.

Disability definition

Wheelchair users referred to in this study fall under the category of disabled users. The definition of the term 'disability' varies from each literature in order to best define the group of people needed for that study. This report will define disability in line with the definition provided by the UK government in the 2010 Equality Act and that provided by the World Health Organisation. An individual is defined as disabled if they have a "physical or mental impairment that has a substantial and long-term negative effect on their ability to execute normal daily activities" Equality Act (2010). The definition used by the World Health Organisation starts similarly but expands further by referring to disability as "not just being a health problem, but a complex phenomenon reflecting the interaction between features of a person's body and features of the society in which he or she lives," (WHO). With air travel being seen as the feature of society that a passenger with disabilities is confronted with. For the purpose of this study, a combination of these definitions was considered, as the aim was to facilitate travel by aircraft, and provide a more enjoyable and less intimidating experience for wheelchair-users.

Associated regulations

The regulation that was considered for this design is those enforced by the United Nations (UN), European Union (EU) and the United Kingdom (UK) government. The UN Convention on the Rights of Persons with Disabilities (CRPD) encourages the research into "universal design" which is defined as the "design of products… to be usable by all people without the need for adaption." (UN, 2006). CRPD aims to promote the idea of universal design, at minimal cost, to meet the needs of a person with disabilities and the development of using universal design in industry standards and guidelines. In 2006 the European Commission (EC), an institution of the EU, published regulation EC No 1107/2006 concerning “the rights of disabled persons and persons with reduced mobility when travelling by air,” (EC, 2007). The regulation states that individuals with disabilities have the same right as all EU citizens for free movement, which is applicable to air travel. In 2011 the EC published COM/2011/0166 a report analysing the success of the implementation of the regulation EC 1107/2006 (EC, 2011). While the application of the regulation overall made travel easier for individuals with disabilities, there were problems concerning passengers being able to use the toilet. The report acknowledged the “difficulties in implementing the regulation also as regards to in-flight assistance, in particular, assistance in moving to toilet facilities, which is the air carrier's responsibility.”

Design

The final design resulted in the Aircraft Combination Wheelchair Seat (ACWS). Figure 1 shows rendered views of the final product.

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Figure 1. Rendered views of the Aircraft Combination Wheelchair Seat (ACWS) in (a) front view, (b) back view, (c) front detached view.

Design function and features

Design function

The ACWS functions as an ordinary aircraft seat when locked into position, seen in Figure 1a. In this position, the foot support can slide back and the wheelchair is held to the seat frame by the locking mechanism which stops one direction of motion, the other is stopped by the sides of the seat frame.

When the wheelchair needs to be released from the frame, the handle that releases the locking mechanism is pulled, and the passenger's wheelchair is then mobile. The foot support can be used throughout the flight and not just when in motion as a means to support body weight. The four sets of twin caster heavy-duty wheels allow 360° rotation and therefore the wheelchair can be turned into any orientation. When the wheelchair needs to be reattached to the seat frame, once positioned in line with the seat frame, it slides into place and the locking mechanism is used to secure it.

The seat frame can be redesigned into any shape to keep coordinate with the commercial airlines' aesthetic. This means that the ACWS can be implemented into current aircrafts as well as future aircrafts. The cushions are covered with a non-flammable material that would be specified by the airline. The bottom cushion can be removed as it is attached to the wheelchair through Velcro. At present, it is common for passengers with disabilities to bring their own wheelchair cushion, which they can use by removing the bottom cushion.

The ACWS will have the standard lap belt used when a passenger with no disabilities is using the chair. However, there will also be a body harness that can be used by the passenger with disabilities to keep themselves upright. This is because passengers with disabilities often ask their companion to hold them upright and use their hand to push away from the seat in front (Davies & Christie, 2017). This body harness would be kept behind the back support cushion of the wheelchair, which is also attached to the wheelchair through Velcro.

Once the ACWS is purchased by the commercial airlines, further design collaboration will take place in order to implement standard functions of the airlines' seats, for example, reclining features, TV screens with associated armrest remote and leaflet pockets. At this stage, the material specified by the airline would be used to cover the back lightening holes of the ACWS.

The release handle and foot support have been dyed yellow. This is following the guidelines of the Disabled Persons Transport Committee's (DPTAC) design specification for the on-board wheelchair for commercial passenger aircraft (DPTAC, 2007). It states that handling points and controls should be marked in contrasting colours. The DPTAC also requires that there are no sharp corners or edges. This is why all the edges have been filleted to at least 2 mm.

Design features

Figure 2 shows the design features of the ACWS with reference to the description in Table 1.

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Figure 2. Annotated design features of the Aircraft Combination Wheelchair Seat (ACWS). To be used in conjunction with Table 1 describing the design features.

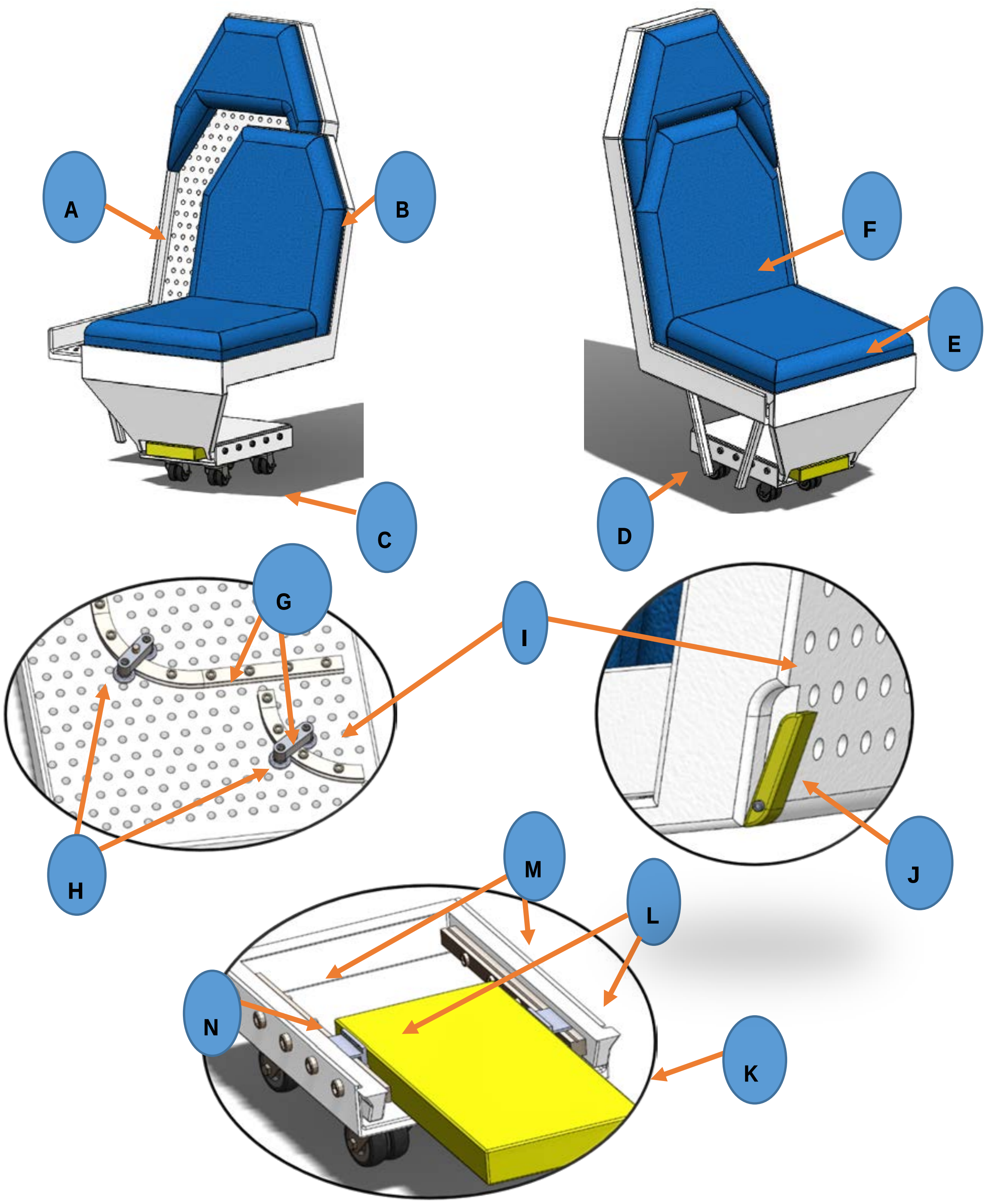

Table 1: Description of the design features of the Aircraft Combination Wheelchair Seat (ACWS) with locations seen in Figure

Location	Design Feature	Description
A	Stationary Seat Frame	A seat frame was needed to be able to house the detachable wheelchair (B) and secure it in place for the duration of the flight. This means that the seat can also be used by a non-disabled passenger.
B	Detachable Wheelchair	The wheelchair was designed to be detachable and to be used when needed. It is able to fit snugly and securely into the seat frame (A).
C	Wheels	4 sets of twin heavy duty caster wheels would be purchased from a supplier and evenly distributed on the bottom on the wheelchair. The wheels have 360^{O} rotation and should not need replacement during the lifetime of the ACWS. They will be screwed into the bottom housing (N).
D	Seat Frame Legs	2 legs have been designed on the window side seat frame to be able to stabilise and hold the weight of the seat frame (A) while wheelchair (B) is detached. There are no legs on the aisle side of the ACWS as would interfere with the movement of the wheelchair.
E	Bottom Cushion	The bottom cushion was designed to be 8 cm thick, as recommended by Ragan et al. (2002), showing this to be the optimal height. It is attached to the wheelchair (B) with Velcro as to be removed if the passenger with disabilities chooses to use their own cushion.
F	Wheelchair Back Cushion	The back cushion of the wheelchair (B) is also attached with Velcro. This is to allow the implementation of a body harness the passenger with disabilities requests one to hold their upper body during landing or turbulence.
G	Curved Linear Roller Guide Rails	The curved linear roller guide rails were chosen as to allow smooth movement of the wheelchair. The guide rails are screwed into the seat frame (A). They would be purchased from a supplier and should last the lifetime of aircraft.
H	Curved Linear Rollers	Ball-bearing rollers that are bought together with the guide rails (F). They move with each other to ensure smooth transitions of the passenger with disabilities. The rollers are attached to the wheelchair (B) and are used to align the wheelchair (B) back to the stationary frame (A).

Location	Design Feature	Description
I	Lightening Holes	The wheelchair lightening holes were added as a weight reduction technique, reducing 7.59 kg. This will improve the fuel economy of the aircraft and in turn, save the airline money. The holes were iteratively designed to be 12 mm on the seat frame (A) and 15 mm on the wheelchair (B).
J	Locking Mechanism Handle	The handle is connected to the locking mechanism that securely connects the wheelchair (B) to the seat frame (A). When the handle is pulled back the handle releases, the spring clamp mechanism and the wheelchair (B) can be moved along the curved linear guide railings (G). When wheelchair (B) needs to be reattached, the clamp is forced open and keeps the wheelchair (B) in place.
K	Foot Support	The foot support was added in accordance with the DPTAC guidelines (2007) to help take the weight of the lower body of the disabled passenger. It can be slid back into the hole between the wheelchair (B) and bottom housing (N) when not required.
L	Linear Rollers	These linear rollers will be used to move the foot support (K) in and out of the wheelchair housing (N). They will be screwed onto the foot support (K).
M	Linear Roller Guide Rails	These straight linear guide rails will be purchased with the linear rollers (L) for movement of the foot support (K). They will be screwed into the wheelchair (B).
N	Bottom Housing	The bottom housing was designed to allow assembly of the ACWS. It will be placed around the bottom of the wheelchair (B) and screwed in.

Aesthetics and ergonomics

Aesthetics

The concept of universal design relates to the aesthetics of a product. This is because instead of having two products that perform similar tasks but for different demographics, they are incorporated into one product that allows both functions to take place. This is portrayed in this design by instead of having an airline seat in place and a wheelchair stored on-board, the ACWS was designed to allow both functions to take place. This reduces storage on the aircraft, which in turn can additionally improve the aesthetics of the interior of the aircraft.

To ensure that the ACWS appears to be aesthetically pleasing, it was designed with a line of symmetry down the middle. This is pleasing to the eye as well as reducing the assembly and manufacture time. The locking mechanism handle was designed to be in line with the side of the ACWS instead of perturbing for aesthetic purposes as well as to avoid catching people walking past the ACWS.

The overall aesthetics of the ACWS would be designed in accordance with the commercial airline that purchases the product. This is because further design collaboration will take place to ensure the shape matches the airline's preference as well as the colour scheme. Furthermore, additional airline seat functions can be included such as reclining features, TV screens with associated armrest functions and leaflet pockets.

Ergonomics

The ergonomics of ACWS were important to consider to ensure dimensional feasibility is used in the tight restrictions of an aircraft. The starting point of the design process was using the seat dimensions of an Airbus A321 (AIRBUS, Blagnac Cedex, France) and iteratively designing the ACWS to ensure it meets these constraints. Figure 3 shows a sketch of the interior of an Airbus 321 aircraft aligned with the ACWS, demonstrating that the ACWS adheres to the dimension requirements.

Figure 3: Sketch of interior of Airbus A321 with ACWS (a) showing the cross-section and (b) showing seat pitch.

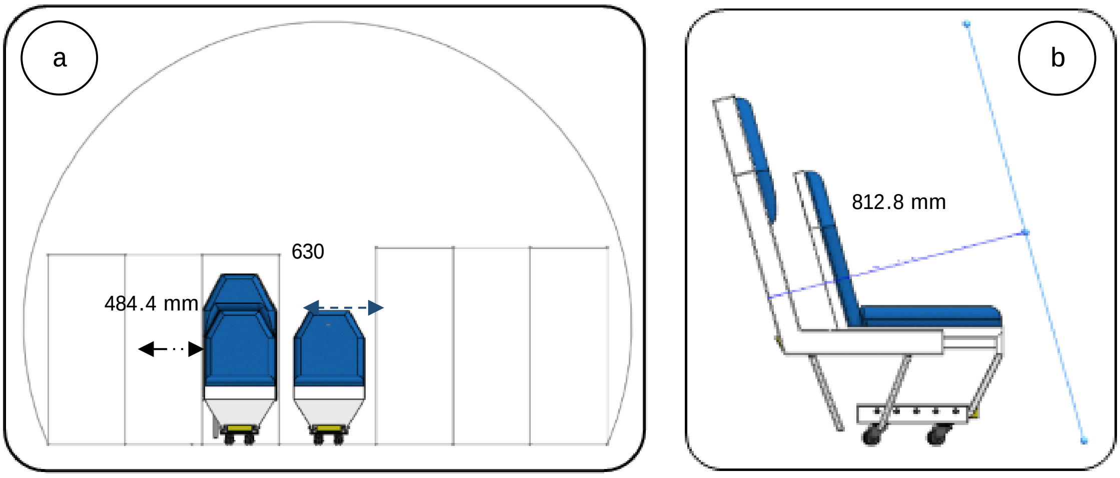

Figure 3a shows the width of the Airbus A321 seat, which equates to 485 mm, in comparison the ACWS has a width of 484.4 mm. Furthermore, the width of the aisle is 630 mm, thus the proposed wheelchair can comfortably be used in the aisle and there is adequate room for the wheelchair to be detached and reattached with the passenger with disabilities in position. The seats pitch is 812.8 mm, which is defined as the measurement from the back panel of a passenger's seat to the back panel of the seat in front. Figure 3b demonstrates that when the wheelchair is detached from the ACWS, there is still a clearance of 144.4 mm between the wheelchair and the seat in front for the passengers with disabilities' legroom.

Material selection

Material selection was carried out on all the components that would be manufactured specifically for the Aircraft Combination Wheelchair Seat (ACWS), which was identified as the detachable wheelchair frame, the stationary seat frame and the foot support platform, thus focusing on the larger more complex components. The material selection was completed using CES EduPack (Granta Designs Ltd., Cambridge, UK) such that a broad range of materials were evaluated simultaneously.

Background research concluded that aluminium is commonly used for the main supporting structure of aircraft seats (Kokorikou, 2016), however, lightweight thermoplastic composites (Veazey, 2017) are growing in popularity. These materials were used as the basis for the selection process with the influencing factors being density, cost and strength.

Selection process

Seat frame and wheelchair frame

The same material was selected for the stationary seat frame and detachable wheelchair frame. This was decided on the basis that the spring locking mechanism locks the detachable wheelchair into position on the stationary seat frame as required. In line with the materials currently used for aircraft seats, the appropriate choices for both the frame material are either aluminium or thermoplastic. A combination of different materials was avoided as this would increase the manufacturing costs, since additional equipment would be required for the different processing techniques.

The mass and cost of the ACWS need to be minimised so that the overall weight of the product compared to that of the standard aircraft seat is not significantly increased, and it is still profitable with airline providers. Furthermore, the strength of the stationary seat frame must be sufficient in order to withstand the mass of the fully-loaded detachable wheelchair. Equations 1-4 were used for the analysis.

$$\boldsymbol{mass} = \boldsymbol{volume} * \boldsymbol{density} \text{ (1)}$$

$$\boldsymbol{where\ volume} = \boldsymbol{area} * \boldsymbol{length} \text{ (2)}$$

$$\boldsymbol{yield\ stress} > \frac{\boldsymbol{force}}{\boldsymbol{area}} \text{ (3)}$$

The area can be eliminated from the equation since it is a constant of the design. Therefore;

$$mass > force * length * \frac{density}{yield\ stress} \quad (4)$$

Hence the mass of the ACWS can be minimized by maximizing the (yield stress)/(density) ratio. The design requirements were determined and subsequently entered into CES Edupack as constraints and objectives. An initial tree stage was applied as to only consider either Aluminium alloys or thermoplastics, depending on which were being analysed. A limit stage was applied to refine the material properties, as shown in Table 2.

Table 2: Material Property Constraints used in CES Edupack

Property	Constraint	Explanation
Yield Strength	3 MPa	Minimise yielding
Young's modulus	3.5 MPa	Minimise deflection
Recyclable Metal	Yes	Not impact the environment
Casting (only Al Alloys)	Excellent, Good	As casting most appropriate primary process for metals based on
Polymer Injection Moulding (only thermoplastics)	Excellent, Good	geometry As injection moulding most appropriate primary process for thermoplastics based on geometry
Flammability	Self-extinguishing, Non-Flammable	Requirement for materials in airlines (FAA,1986)

The analysis concluded that the most appropriate materials for the seat and wheelchair frame were Aluminium A206 or Polyetherketoneketone (PEKK). The material properties are summarised in Table 3 and 4. Further analysis concluded that although the initial material cost price for PEKK is much higher in comparison to Aluminium A206, the fuel burnt saving for the lifetime of the aircraft is higher (Red, 2014), which can be 25-30 years depending on the manufacturer (Maksel, 2008). Furthermore, the mass of PEKK compared to Aluminium A206 is quoted as approximately less than half. Therefore, for the purpose of this study, PEKK was selected as the material of choice for the frame.

Table 3: Material Properties for Aluminium, A206.0, permanent mould cast T7.

Property	Value	Midpoint
Price	1.57 - 1.67 GBP/kg	1.62 GBP/kg
Density	$2.77*10^3$ - $2.83*10^3$ kg/m^3	$2.80*10^3$ kg/m^3
Young's Modulus Yield	69.4 – 71 GPa	70.2 GPa
Strength (elastic limit)	333 – 357 MPa	345 MPa

Table 4: Material properties of PEKK (unfilled, semi-crystalline)

Property	**Value**	**Midpoint**
Price	65.8 - 73.4 GBP/kg	69.9 GBP/kg
Density	$1.3*10^3$ – $1.32*10^3$ kg/m^3	$1.31*10^3$ kg/m^3
Young's Modulus Yield	4.29 – 4.52 GPa	4.405 GPa
Strength (elastic limit)	135 - 141 MPa	138 MPa

One other important factor is the material used to create the cushion. This is particularly relevant for passengers with disabilities since one of the causes of pressure ulcers is related to being seated on an inappropriate surface for long periods of time (Schmeler, 2000). The cushion is used to redistribute forces away from the bony prominences by decreasing the magnitude of pressure (Sonenblum, 2014).

In summary, these all tend to be a firm, lightweight form of foam that is easily cut to the correct size and shape. As the requirements for cushion material is not quantifiable but rather assessed by how the material performs through experimentation, a selection process using CES Edupack was not deemed appropriate. The cushion material was chosen based on research and experimental analysis.

Several studies have concluded that while personal preference for each individual wheelchair user in terms of cushion material is likely to vary, overall the ROHO brand cushions is the most effective under average test conditions (Sonenblum, 2014; Yuen, 2001). The use of the ROHO brand of cushions was considered in this study however, since the range of ROHO products enables bespoke selection for each intended user, a brand selection was disregarded and deemed inappropriate. The focus instead was placed on the material used to manufacture the ROHO cushions, which was identified as polyurethane foam (ROHO, Belleville, IL 62221-5429, USA). Furthermore, the analysis of polyurethane foam using CES Edupack concluded that the material is suitable for use in aircrafts. The material properties of the polyurethane foam (elastomeric, open cell, 0.024) is shown in Table 5.

Table 5: Material Properties for Polyurethane foam (elastomeric, open cell, 0.024)

Property	Value	Midpoint
Price	4.88 – 5.37 GBP/kg	5.13 GBP/kg
Density Relative	26 – 32 kg/m^3	29 kg/m^3
Density	0.02 – 0.025	0.0225
Flammability	Slow-burning	N/A

Since polyurethane is deemed a slow-burning material, a non-flammable cover has been selected, which is consistent with airline regulations (FAA, 1986). Furthermore, studies have concluded that the benefits of a cushion thickness greater than a 80 mm plateau is negligible since pressure sores that develop using a cushion at this thickness is in fact attributed to other factors, for instance, seating posture or cushion material (Ragan, 2002). This was considered in the final design of ACWS, where a cushion thickness of 80 mm can be seen.

Manufacturing process

PEKK components

The Aircraft Combination Wheelchair Seat (ACWS) components, manufactured from PEKK are the seat frame, wheelchair, release handle, foot support and bottom housing. PEKK is a suitable material for both additive manufacturing (Scott, 2017) and injection moulding as primary processes. However, due to the complexities of the components, additive manufacturing would increase manufacturing time and cost. Therefore, it is recommended that the PEKK components are manufactured using injection moulding as the primary manufacturing process. The secondary processes that can be applied to PEKK include turning, boring and grinding, to create the lightening holes, screw holes and filets on all the PEKK components.

Polyurethane foam components

The components made from polyurethane foam are the three cushions. The foam is bought from the suppliers in sheets with the specified thickness. Hot wire or water jet cutting can be used to shape the cushions. It is recommended that the cushions are covered in a non-flammable material specified by the airline provider. Once covered, no further processes will need to be applied to the polyurethane foam cushions.

Assembly plan

The assembly plan for the ACWS is summarised in Table 6.

Table 6: Assembly Plan for the ACWS

Task	Parts	Description
1	Seat Frame, Curved Linear Roller Guides	Line up the guide rails with the 10 mm holes on the seat frame, with the shorter rail on the aisle-side. Screw in the 10 mm screws from the supplier with a screwdriver and tighten with a wrench.
2	Wheelchair, Curved Rollers	Line up the rollers on the underside of the wheelchair with the 10 mm holes. Screw in 10 mm screws with screws from the supplier using a screwdriver.
3	Wheelchair, Straight Linear Roller Guides	Line up the 8 mm screws with the holes on both sides of the wheelchair. Screw in the 8 mm screws from the supplier with a screwdriver and tighten with a wrench. Apply back roller stops.
4	Straight Rollers, Foot Support	Line up the rollers on the sides of the foot support with the 3 mm holes. Screw in 3 mm screws with screws from the supplier using a screwdriver, tighten with a wrench.

Task	Parts	Description
5	Bottom Housing, Wheels	Line up the wheels with the 5 mm holes in the bottom housing. Screw in the 5 mm screws using a screwdriver and tighten with a wrench.
6	Bottom Housing, Wheelchair	Line up the back of the bottom housing with the back of the wheelchair. Screw in the 12 mm holes and tighten with a wrench.
7	Foot Support, Wheelchair	Slide the linear roller on the linear guide rails and apply front stops.
9	Bottom Cushion, Velcro, Wheelchair	Remove the cover from Velcro strips and apply one side to wheelchair and other to bottom cushion. Ensure strips are lined up. Place the bottom cushion on the wheelchair.
10	Wheelchair, Velcro Wheelchair Back Cushion	Remove the cover from Velcro strips and apply one side to wheelchair and other to wheelchair back cushion. Ensure strips are lined up. Place wheelchair back cushion on the wheelchair.
11	Locking Mechanism, Seat Frame, Release Handle Seat	Connect the locking mechanism to the handle. Place the locking mechanism in the seat frame, with handle in place.
12	Back Cushion, Seat Frame	Attach the seat back cushion to the seat frame.
13	Wheelchair, Seat Frame	Line up the curved linear rollers with the curved rollers and apply stops. Push the wheelchair into the locking mechanism

Analysis

To validate that the Aircraft Combination Wheelchair Seat (ACWS) is appropriate in both design and material selection, Finite Element Analysis (FEA) was carried out on the critical components. This is to determine possible areas of stress failure and to examine stresses within the structure. FEA was also used to validate whether the lightening holes incorporated into the wheelchair and seat frame were technically feasible. The critical components were deemed to be the seat frame and the wheelchair manufactured from PEKK with the FEA software used being Abaqus CAE (Dassault Systémes, Paris, France). The Disabled Persons Transport Advisory Committee's (DPTAC) Design Specification for On-Board Wheelchair for

Commercial Passenger Aircraft states that testing loads on the wheelchair should take place at 2.5 kN evenly distributed across the base of the wheelchair, which was used for the ACWS. The analysis took place on the wheelchair when detached and then locked into the seat frame. The seat frame was not analysed in isolation as it is not intended that it would be loaded in this way.

Analysis of solid components

Initially, the solid components were analysed to ensure that the design itself was technically feasible. If a failure occurred at this stage, the ACWS was improved to prevent this. Methods used included increasing the thicknesses or angle that the wheelchair bends into the bottom housing.

Solid detached wheelchair

The solid wheelchair CAD model was imported into Abaqus and meshed using tetrahedron shaped meshing elements. This shape is commonly used for complex 3-dimensional models. The mesh of the solid wheelchair is shown in Figure 4a.

The mesh consisted of 18,312 nodes, which equated to 9324 tetrahedral elements. The boundary conditions set at zero rotation and displacement were at the base of the wheelchair where it meets the bottom housing. The boundary conditions and where the model was statically loaded is seen in Figure 4b.

The model was run, and the results examined to ensure that the maximum stress on the wheelchair did not exceed the yield strength elastic limit of PEKK. The deformed model with the Von Mises stress measurement is seen in Figure 4c.

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Figure 4: (a) FEA mesh used for the solid detached wheelchair in isolation; (b) Boundary conditions and load applied to the detached wheelchair; (c) Deformed solid detached wheelchair showing maximum stress concentration.

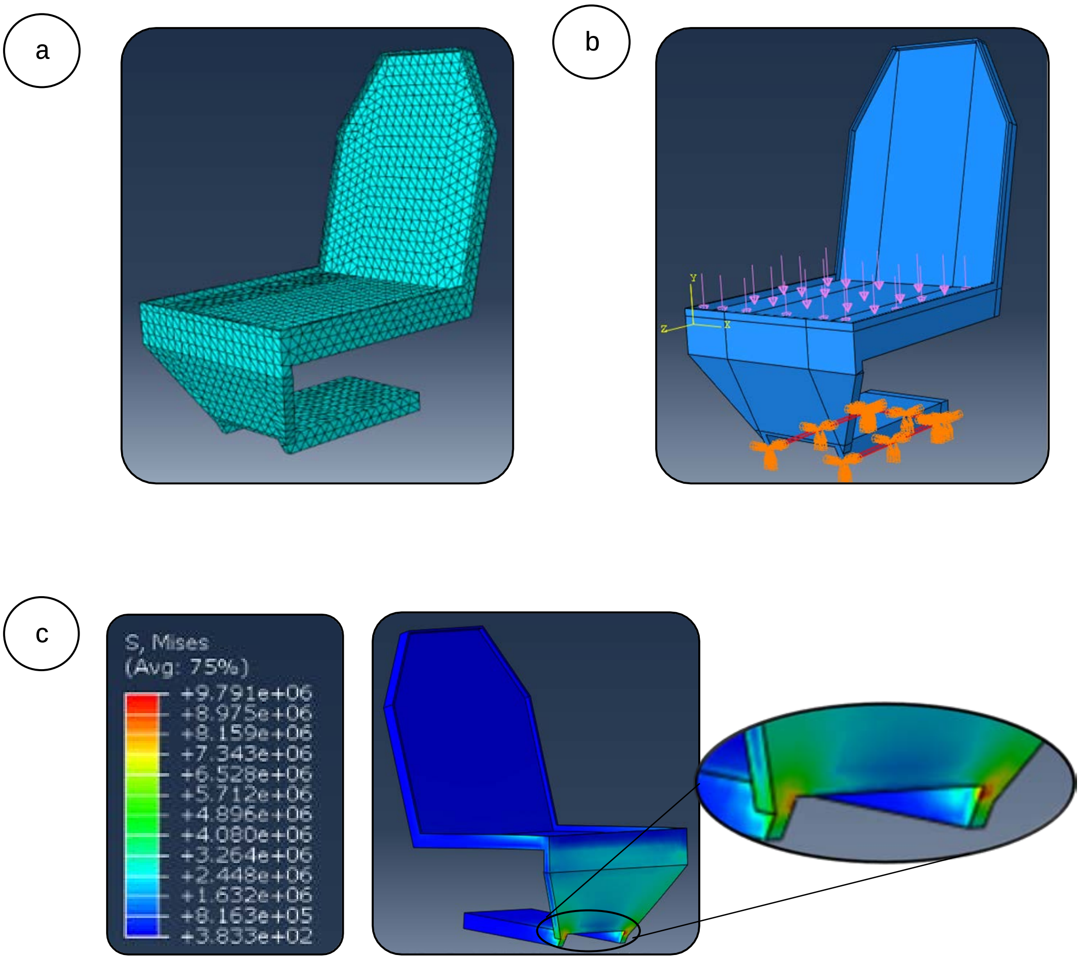

Figure 4c shows that maximum stress on the solid wheelchair occurs at the corners of the hole where the foot support is housed. In comparison to the yield strength elastic limit of PEKK (138 MPa), the stress at these corners is much lower. Therefore, based on this favourable difference, it was concluded that since the maximum stress on the loaded wheelchair is not comparable to the yield strength elastic limit of PEKK, this material selection and design was technically feasible.

Solid wheelchair locked into the seat frame

The next model created and analysed, demonstrated how the wheelchair locked into the seat frame. This model was meshed using the same tetrahedral shapes, seen in Figure 5a.

This mesh consisted of 46,377 nodes equalling 24,575 elements, which was higher in comparison to the scenario of the wheelchair being analysed in isolation. This can be explained by the fact that the approximate size of the elements were kept the same. The same boundary conditions were set, as compared to the wheelchair in isolation scenario, except that in this new scenario, the bottom of the seat frame legs has been incorporated into the CAD model as shown in Figure 5b.

The loaded model was then run to ensure that the passenger could remain safely seated on the seat. The deformed model with the Von Mises stress measurement is shown in Figure 5c.

The results concluded that when locked into position, the maximum stress concentration occurs on the inner side of the back seat frame leg. This can be explained by the greater force experience in this location from the evenly distributed 2.5 kN load as well as the mass of the back panel of both the seat frame and wheelchair. This can be rectified by thickening the cross-section of the leg and filleting the corners to 2 mm. Overall the model can still be determined technically feasible as the maximum stress concentration seen in the key is 3.5 MPa and the yield strength elastic limit of PEKK in comparison is 138 MPa.

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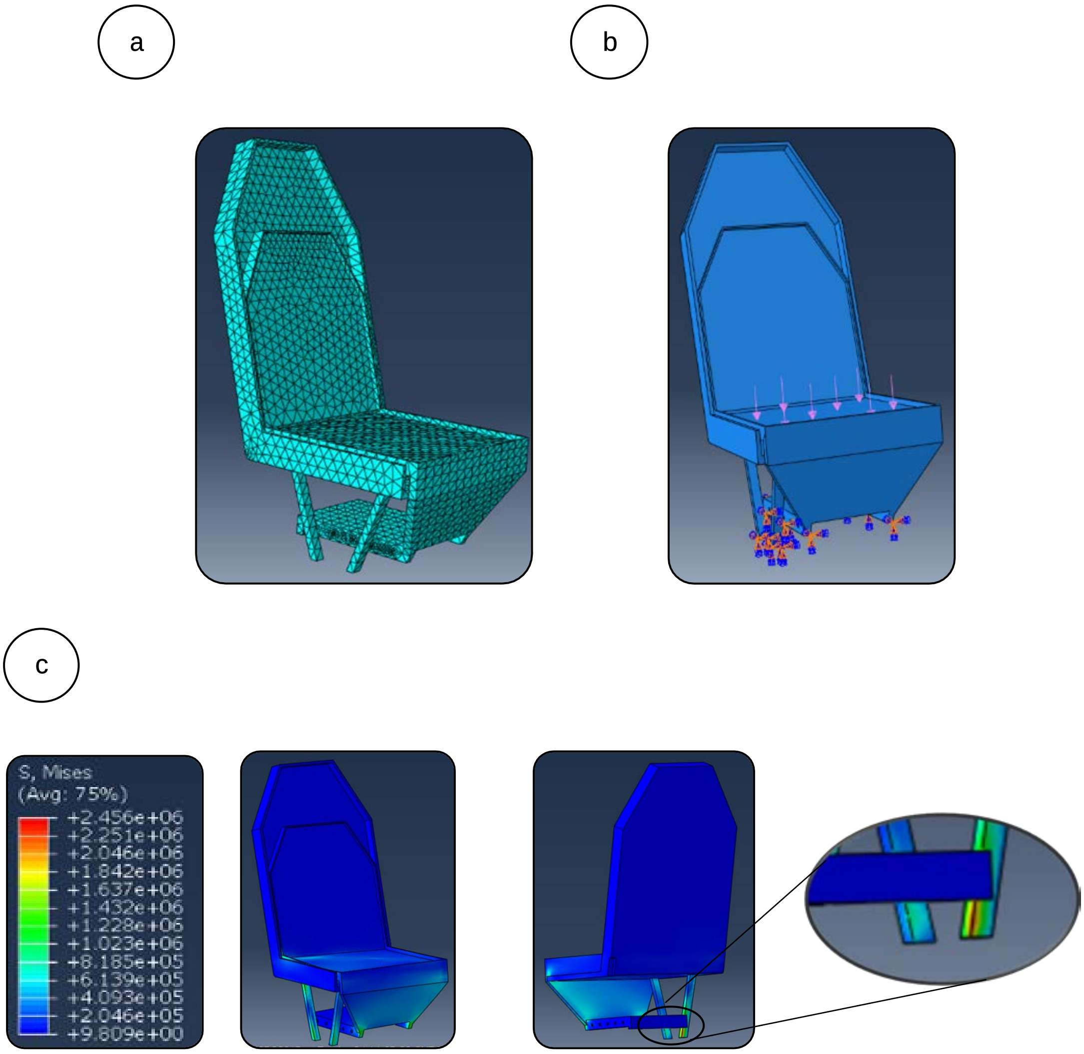
Figure 5: (a) FEA mesh used for the solid wheelchair locked into seat frame; (b) Boundary conditions and load applied to the solid wheelchair when locked into seat frame; (c) Deformed solid wheelchair locked into seat frame showing maximum stress concentration.



From both the scenarios, the loaded wheelchair analysed in isolation and then locked into the seat frame, the maximum stress concentrations did not approach the yield strength elastic limit of PEKK (138 MPa), thus the product was determined technically feasible. The maximum greater stress experienced on the detached wheelchair when it is locked into the seat frame can be explained by the additional support that the seat frame legs provide. This is shown in Figure 5c as stress has decreased across the front sweep of the wheelchair and is experienced on the seat frame legs.

Analysis of components with lightening holes

The use of lightening holes can be seen in both the aviation and automotive industry (Sawyer, 2012; Vellaichamy, 1990), whose function is to reduce mass while maintaining sufficient strength. The driver for these industries to use mass saving methods is to reduce fuel consumption of the respective vehicles (Jemiolo, 2015), with the ultimate motivation for improving design features being a reduction in costs. In order to meet the criteria of the product design specification, the use of lightening holes to reduce the mass of the ACWS was investigated on both the seat frame and wheelchair.

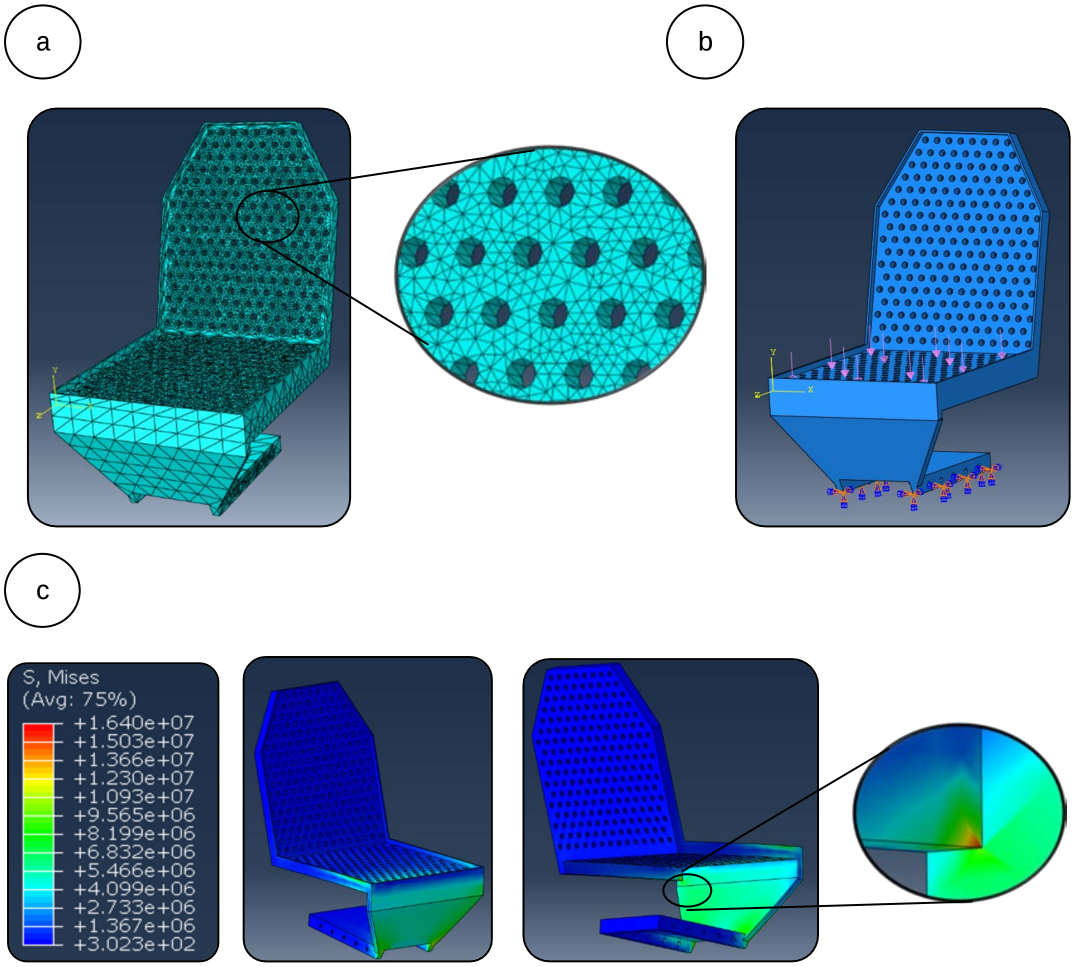
Detached wheelchair with lightening holes

The wheelchair lightening holes were chosen to have a diameter of 15 mm with holes in the same row being 30 mm away as well as the distance of the rows being 30 mm. This resulted in a mass saving of 5.41 kg. The mesh of this model used tetrahedral shapes which can be seen in Figure 6a.

The mesh of this model consisted of 213,342 nodes which equates to 131,128 elements. This is greater than that reported for the solid models due to the lightening holes needing to be meshed as well as the face meshes, thus increasing in complexity. The boundary conditions and load were kept the same as the solid wheelchair to ensure a consistent testing method, seen in Figure 6b.

This model was then run to determine if the implementation of the lightening holes were technically feasible, seen in Figure 6c.

Figure 6: (a) FEA mesh used for the detached wheelchair with lightening holes; (b) Boundary conditions and load applied to the detached wheelchair with lightening holes; (c) Deformed detached wheelchair with lightening holes showing maximum stress concentration.



The maximum stress concentration shown by the inset of Figure 6c occurred at the inner corner, underneath the loaded position of the wheelchair. This would be due to the shape of this ledge, used to cover the gap between the wheelchair and seat frame when attached. This stress concentration would be rectified by filleting the ledge. Overall, it can be seen that the detached wheelchair with lightening holes has stress concentrations that are below the PEKK yield strength elastic limit of 138 MPa.

Wheelchair locked into seat frame with lightening holes

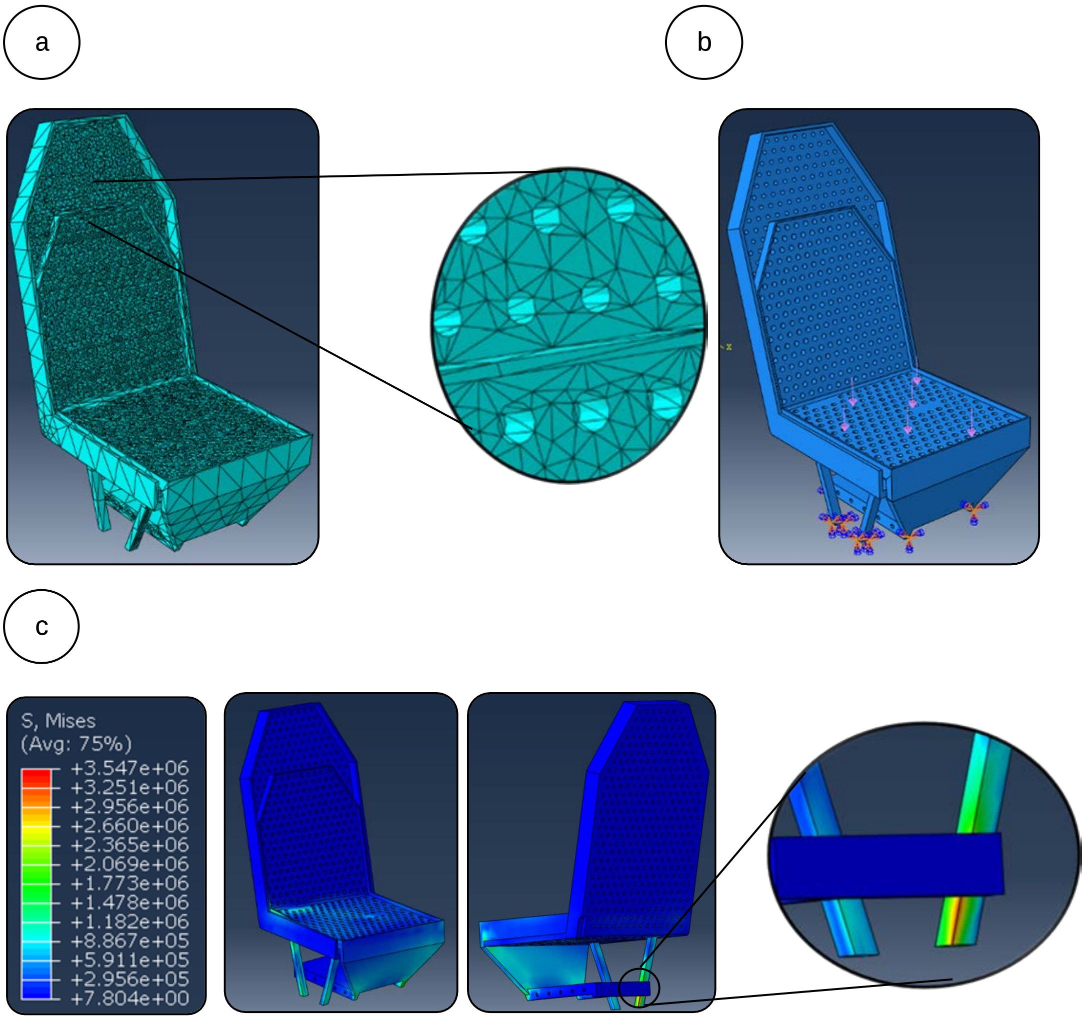
The wheelchair with lightening holes was then modelled as being locked into the seat frame as per previous analysis when the solid components were analysed. Lightening holes with a diameter of 12 mm and with holes in the same row being 30 mm away as well as the distance of the rows being 30 mm, were incorporated into the CAD model. This gave a mass saving of 2.18 kg, thus a total mass saving of the ACWS to be 7.59 kg. As shown previously for the other scenarios, the mesh of this model used tetrahedral shapes which can be seen in Figure 7a.

This mesh consisted of 228,379 nodes equating to 134,891 elements, thus producing the largest mesh due to both the wheelchair and frame being incorporated into the CAD model and the presence of the lightening holes. To ensure a consistent testing method, the boundary conditions and load, seen in Figure 7b, were the same as the model with no lightening holes, discussed previously.

From there the model was run to deem if the lightening holes on both the seat frame and wheelchair were technically feasible. The results are summarised in Figure 7c.

This maximum stress concentration of this model similarly occurs at the inner wall of the back legs of the seat frame. This can be rectified by thickening the cross-section of the leg and filleting the corners to 2 mm. However, this stress concentration is still below the PEKK yield strength elastic limit of 138 MPa.

Figure 7: (a) FEA mesh used for the wheelchair locked into seat frame, both with lightening holes; (b) Boundary conditions and load applied to the solid wheelchair when locked into seat frame, both with lightening holes; (c) Deformed solid wheelchair locked into seat frame, both with lightening holes, showing maximum stress concentration.



From this model and the detached wheelchair with lightening holes, the max stress does not reach the 138 MPa yield strength elastic limit of PEKK, thus the ACWS design and the selection of PEKK can be deemed technically feasible. Furthermore, varying the size of the elements and the nodes did not alter the results substantially.

Conclusions

The challenges in disabled travel experiences are well documented in the literature. The increasing adoption of equality and diversity measures within the society and the use of air travel by both abled and less abled passengers, has driven the development of this Aircraft Combination Wheelchair Seat (ACWS). This study presented a conceptual design, explained the mechanisms of the ACWS design and analysed the design. The novelty of the design is the dual function of its use as an ordinary aircraft seat when locked into position and as a wheelchair when it is disengaged. The suggested ACWS meets the requirements of the dimensions of the Airbus A321 aircraft aisles and facilitates aircraft mobility. FEA analysis concluded that the choice of PEKK and the use of lightening holes was technically feasible.

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DESIGNING UNIVERSAL VISUOTACTILE PICTOGRAMS FOR ORIENTATION MAPS

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***Abstract*:** Pictograms are used in all domains of our daily life, in orientation maps in particular. They can be depicted visually or tactually for blind people. The problem is that these existing pictograms are not standardized. The aim of this study was to develop a range of visuotactile orientation pictograms, which would be understandable by adults, children, elderly, foreigners and people with visual disability. We conducted three studies: Study 1 aimed to make sighted users (adults and children) evaluate a set of visuotactile pictograms designed initially for blind users concerning their perceptual and cognitive processes. The results show that many of these pictograms proved to be too specific to be understandable by the general population. To complement the data, we analyzed the impact of colours on the understanding of pictograms by sighted users (Study 2). Finally, we conducted a series of creative workshops with sighted adults, blind adults and sighted children (Study 3) in order to generate a new set of universal visuotactile pictograms. This research contribution is twofold: from a methodological viewpoint, we experienced and observed the limitations of two approaches (top-down and bottom-up) to design universal pictograms.

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From a practical viewpoint, we created a set of universal visuotactile pictograms to make orientation maps more accessible.

Relevance to industry: Both the methodological insights and the design results can be useful to practitioners. Our proposal of the new set of universal visuotactile pictograms can be used by sign makers to design accessible orientation maps.

Keywords: Universal design; accessibility; visuotactile pictograms; orientation maps; people with visual disability

Introduction

Pictograms are usually used in daily life, in signage in particular, for example, to indicate toilets in a museum. "*They are used to replace written indications and instructions expressing regulatory, mandatory, warning and prohibitory information in order to process information quickly, to help foreigners or persons having limited linguistic ability, or having visual problems (e.g. older people)"* (Tijus et al., n.d.). Pictograms are defined as: "*a stylized figurative drawing that is used to convey information of an analogical or figurative nature directly to indicate an object or to express an idea".* Pictograms are categorized according to their links with the object represented (Tijus et al., 2005):

- *Figurative pictogram*: the signified object or situation is reproduced more or less faithfully or schematized, supplying physical clues to facilitate comprehension (e.g., fork and knife to symbolize a restaurant).
- *Abstract pictogram*: the signified object or situation of reference is evoked through abstract graphic concepts which reproduce some of its features or functions, (e.g., the up and down arrows for the lift).

- *Arbitrary pictogram*: the signs used in the pictogram have a symbolic meaning possibly influenced by cultural factors (e.g., the dove symbolizing peace).

Pictograms are supposed to have a strong evocative potential with a significant metaphorical ability (Brangier & Gronier, 2000). It is generally accepted that pictograms are universal, recognizable and memorable by all people (Lodding, 1983; Wickens, 1992; Vaillant, 1997; Weidenbeck, 1999; Bordon, 2004). This explains why they are widely used in the medical field to improve medication information comprehension by adults, children, elderly or illiterate people (Houts et al., 2006; Thompson et al., 2010; Barros et al., 2014). Many studies in the field of illiteracy and dyslexia showed that pictures, graphics and pictograms facilitate access to information (Medhi, Sagar, & Toyama, 2005; Parikh, Ghosh & Chavan, 2003a, 2003b; Huenerfauth, 2002; Grisedale, Graves & Grünsteidl, 1997; British Dyslexia Association, 2009; Rainger, 2003; Gélinas-Chebat, Préfontaine, Lecavalier & Chebat, 1993) provided that they are culturally adapted (Chipchase, 2006; Medhi, Sagar, & Toyama, 2005), clear (Joshi, Welankar, Kanitkar & Sheikh, 2008), significant (Medhi, Menon, Cutrell & Toyama, 2010) and contextualized (Tijus et al., 2005).

Guastello et al. (1989) explain that pictograms with textual information are better understood, especially in complex situations; a strong concordance between the signifier and the signified is of utmost importance, the bigger the distance, the more difficult the understanding.

However, there are no standardized visual pictograms even if, since the 90's the International Standardization Organisation (ISO) has normalized existing pictograms and their creation. For example, the ISO norm 7001 gathers pictograms related to touristic information (e.g., "i" for information). It provides guidelines on the contents (e.g., background colour, size) to enable wayfinding designers to culturally adapt pictograms (Vaillant, 1997). This lack of standardization results in a great variability of pictograms. For example, we can find many graphical representations of toilets, not only the world as a whole but within the same country. This variability involves a learning process each time users are in front of a new graphical representation. This increases the time of visualisation, leading to cognitive load and therefore reducing the efficacy and efficiency (ISO 9241-11) of the pictogram.

Moreover, pictograms can be depicted not only visually but also tactually for blind people. Several combinations of the visual and tactile modalities can be designed: (1) the tactile signifier reproduces the graphical one, which results in a visuotactile pictogram, or, (2) two different signifiers are superimposed, a graphical one and a different tactile one. Currently, no standardized design guidelines exist for tactile and visuotactile pictograms.

In our opinion, this lack of standardization is the reason why in France, orientation maps are not universal and accessible. Each establishment receiving the public (such as museums, Town halls, and so on) has its own orientation maps with its own pictograms designed by differents sign makers. Sometimes, in the same establishment there is an orientation map for sighted people and another for the blind people. Therefore, our issue is to find a common representation for designing visuotactile pictograms, which requires that (1) the graphical representation must be comprehensible by all sighted people in the society (e.g. children, adults, the elderly, people with visual disability and foreigners) and, (2) the tactile representation must be comprehensible by people born blind and those who become blind later in life. Tactile designs involve respecting the criteria of transposability (Bris, n.d), which are:

- *Dimension*: pictograms must be adapted to the surface of the pad of the index finger,
- *No perspective*: perspective is a sighted concept and is not understood by blind people, particularly if they are born blind,

- *Simplicity*: to be comprehensible, pictograms must be simple and straight forward,
- *Discriminability*: each element composing a pictogram must be tactually discriminable, which means that tactile gaps of at least 2mm must be respected between two elements.

These criteria enable blind people to use their own experience, which may be different from accepted visual representations, to interpret pictograms. We intend to design visuotactile pictograms, i.e. to identify a single visual and tactile signifier which would be understandable by sighted and blind users. First, for the purpose of this research, it is assumed that such visuotactile pictograms will be more readable than the superimposition of different visual and tactile signs. Indeed, partially-sighted people may be unsettled in their reading when tactile is not equivalent to visual. Moreover, visuotactile pictograms may save space and reduce the informational load in comparison to juxtaposing two different signifiers on orientation maps. Finally, a single signifier may be more aesthetic than two different signifiers superimposed or juxtaposed.

Our research aims to develop a range of visuotactile orientation pictograms, which would be understandable by everyone(adults, children, elderly, foreigners and people with visual disability).

To achieve our goal, we studied the domain of Universal Design (Vanderheiden, 1997; Vanderheiden & Tobias, 2000) which is defined as follows "*the design of products and environments that can be used by all, to the maximum extent possible, without the need for adaptation or specific design*" (Story, Mueller, mace, 1998). The objective is to consider all audiences in design projects and particularly minimize the risk of stigmatization associated with specific products (Coleman, Lobben, Clarkson & Keates, 2003). To this definition are added seven principles with guidelines (Connel et al., 1997; Figure 1) considering needs of people with disabilities, but also children, elderly users, left-handers, etc. These principles are:

1. *Equitable use*: design a product that is useful and marketable to users with diverse abilities. Guidelines are :
    a. Provide the same means of use for all users: identical whenever possible; equivalent when not.
    b. Avoid segregating or stigmatizing any users.
    c. Provisions for privacy, security, and safety should be equally available to all users.
    d. Make the design appealing to all users.
2. *Flexibility in use*: design a product that takes into account the preferences and abilities of users.
    a. Provide choice in methods of use.
    b. Accommodate right- or left-handed access and use.
    c. Facilitate the user's accuracy and precision.
    d. Provide adaptability to the user's pace.
3. *Simple and intuitive use*: design a product that is easy to use and understandable regardless of prior experience, language skills or education level.
    a. Eliminate unnecessary complexity.
    b. Be consistent with user expectations and intuition.
    c. Accommodate a wide range of literacy and language skills.
    d. 3d. Arrange information consistent with its importance.
    e. Provide effective prompting and feedback during and after task completion.
4. *Perceptible information*: information about the use of the product must be effective.
    a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
    b. Provide adequate contrast between essential information and its surroundings.
    c. Maximize "legibility" of essential information.

   d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).

   e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

5. *Tolerance for error*: the product helps users avoid errors or accidents.

   a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.

   b. Provide warnings of hazards and errors.

   c. Provide fail safe features.

   d. Discourage unconscious action in tasks that require vigilance.

6. *Low physical effort*: the product can be used with minimum effort and fatigue.

   a. Allow user to maintain a neutral body position.

   b. Use reasonable operating forces.

   c. Minimize repetitive actions.

   d. Minimize sustained physical effort.

7. *Size and space for approach and use*: dimensions of use are sufficient for any user.

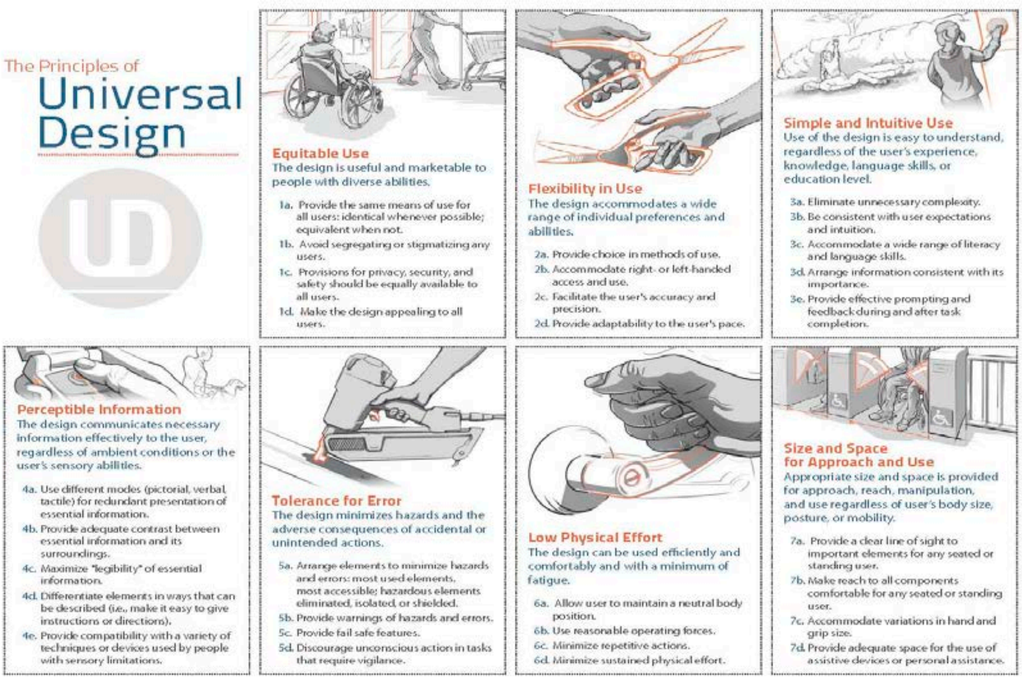
   a. Provide a clear line of sight to important elements for any seated or standing user.

   b. Make reach to all components comfortable for any seated or standing user.

   c. Accommodate variations in hand and grip size.

   d. Provide adequate space for the use of assistive devices or personal assistance.

Figure 1: the principles illustrates of Universal Design.



As part of this research, we focused on the first four principles. In respect of these four principles, we tested our proposal of pictograms with three profiles of users (sighted children, blind and sighted adults). We chose two modalities because of the first principle of the Universal Design for Learning is "Multiple means of representation", according to Rose (2006) "students differ in the ways that they perceive and comprehend information presented to them"(p.136), in this perspective we used two modalities (visual and tactile) to design pictograms. Tests will allow us to consider all capacities and to assure us that pictograms are effectively perceptible and comprehensible.

Two approaches support the design for all people (Stary, 1997; Plos et al., 2007):

- *Top-down (or adaptive) approach*: specialized products are designed to meet the special needs of specific target users, for example, disabled people, then these needs, or these solutions, are extended to other users.

- *Bottom-up (or proactive) approach*: products are designed for the greatest number of users (people who are disabled or not).

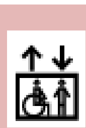
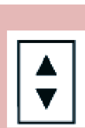
We initially chose to follow a top-down approach: a first set of visuotactile pictograms that were adapted to blind users was designed; then the visual form of these pictograms were evaluated by sighted users from the target population. However, as will be developed next section, it appeared necessary to redesign several pictograms in a bottom-up approach. Below we report on the evaluation process with sighted users (Study 1), a specific analysis of the impact of colours on the understanding of pictograms by sighted users (Study 2) and a series of creativity workshops that were conducted with sighted adults, blind adults and sighted children (Study 3). All studies were conducted in France; participants were French and lived in Paris. We did not include the cultural dimension of pictograms. It is one of the limitations of this research, as discussed in conclusion.

Study 1

An initial set of visuotactile pictograms were designed by several expert designers, including an expert in tactile transcription for orientation maps. These pictograms were intended to account for accessibility constraints, specific cognitive processes of blind users, transposability criteria as well as for existing visual conventions. Over the years and projects, these pictograms were evaluated by several associations (e.g. the National Federation of blind people in France, Valentin Haüy Association) (Boisadan et al., 2016) and proved to be readable and understandable by blind users. Ten concepts were identified (Table 1) by experts of this corporate partner because they are the most common in orientation maps and favour spatial structuring. Various signifiers exist for some of these.

Following this process, the aim of Study 1 was to validate the comprehension of the visual form of these pictograms with the general public (adults and children).

Table 1. Concepts and signifiers adapted to blind users' capacities and representations.

Concepts	Signifiers		
Reception			
Information point			
Stairs			
Access			
Lift			
Toilets			
Scale			
You are here			

Concepts	Signifiers	
Restaurant		
Wind rose	Nord 	N 

Methodology

Participants

Three hundred and twenty seven volunteers participated, including 297 French-speaking adults (mean age = 33,5, Standard Deviation (SD) = 10,58) and 30 French-speaking children (mean age = 9,9; SD = 1,27). Adults were recruited through social networks, and children were recruited from a holiday centre located in Pantin, France.

Material

We created a questionnaire including two parts.

Part 1: The use of orientation maps

Adults participants used a 7-point Likert-type scale to rate their expertise level with regards to orientation maps. They were also invited to fill in two open-ended questions related to the information they expect to find in indoor and outdoor orientation maps. Children were asked if they knew what orientation maps were and if they had already used any.

Part 2: Pictogram identification

Each one of the 19 signifiers was linked to an open-ended question “For you, what does this pictogram represent?”.

Procedure

Adults completed an online survey distributed on various networks (Linkedin, ErgoIHM list, ErgoList), whereas children completed a paper form during individual interviews. The facilitator helped them focus their attention on the pictograms and write their answer.

Data collection

Participants’ answers for each pictogram were coded as correct or incorrect with regard to the intended meaning. For example, for the pictogram “cafeteria”, the answers “cafe” or “bar” were considered as right and “hot drink” or “coffee machine” were judged as wrong.

Results

Part 1: The use of orientation maps

Adults obtained a mean score of 5 (SD = 2) regarding the use of orientation maps; this means that they are regular users of them. In indoor maps, they expect to find: you are here, toilets, service list, access, lift and stairs. Expected information in outdoor maps is: you are here, point(s) of interest, streets, transportation, wind rose and important buildings.

57% of the children had already seen orientation maps; 20% stated occasional use and 13% frequent use.

Part 2: Pictograms identification

In total, 19 signifiers were evaluated. They were classified in three categories (Table 2): 1) recognized by 80% or more participants, 2) intermediately recognized (60 to 79% recognition rate) and 3) not recognized (below 60%).

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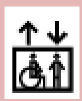
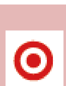
Table 2. Percentage of pictograms identification by children and adults (green: recognized, yellow: intermediately recognized, red: pictograms not recognized).

Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
	Reception		2,71	97,29	3,33	96,67
	Information point		65,76	0,34	23,33	76,67
	Cafeteria	1	88,14	11,86	70	30
	Cafeteria	2	63,39	36,61	40	60
	Cafeteria	3	66,44	33,56	56,67	43,33
	Cafeteria	4	73,90	26,10	30	70
	Stairs	1	4,75	95,25	3,33	96,67
	Stairs	2	13,56	86,44	6,67	93,33
	Access	1	20,68	79,32	3,33	96,67
	Access	2	2,37	97,63	3,33	96,67

Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
		3	0,68	99,32	3,33	96,67
	Lift	1	0,68	99,32	0	100
		2	90,85	9,15	20	80
		3	54,92	45,08	63,33	36,67
	Toilets		91,53	8,47	83,33	16,67
	Scale		71,19	28,81	37	63
	You are here	1	36,95	63,05	16,67	83,33
		2	11,19	88,81	10	90
		3	36,95	63,05	10	90
	Restaurant	1	99,32	0,68	93,33	6,67
		2	90,17	9,83	63,33	36,67

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Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
	Wind rose	1	94,92	5,08	83,33	16,67
	Wind rose	2	84,75	15,25	73,33	26,67

Ten pictograms were not recognized (reception, all signifiers of “stairs”, “access” and “you are here”). Only three pictograms (toilets, restaurant 1 and wind rose 1) were well recognized by adults and children (Table 2). Below we provide an overview of the unexpected interpretations for the pictograms that were not recognized (Table 3).

Table 3. Adults and children interpretations of the pictograms that were not recognized.

Pictograms	Concepts	Interpretation of pictograms not recognized	
		Adults	Children
	Reception	wifi (38%), doesn’t know (20%), panorama (16%)	eye (34%), doesn’t know (16%), network (13%)
	Information point	/	doesn’t know (40%)

Pictograms	Concepts		Interpretation of pictograms not recognized	
			Adults	Children
	Cafeteria	2	/	breakfast (30%), restaurant (21%), eat and drink (12%), bakery (12%)
		4	/	cup (20%), drink (20%), glass (17%)
	Stairs	1	doesn't know (36%), thermometer (17%)	temperature (23%), battery (20%), doesn't know (20%)
		2	doesn't know (55%)	doesn't know (43%), from the smallest to the biggest (10%)
	Access	1	doesn't know (27%)	triangle (40%), direction (15%), wrong way (12%)
		2	doesn't know (42%), distance (12%)	doesn't know (20%), right-left (17%), quotation marks (10%), big and small (10%)
		3	Up-going elevator (28%), going up (26%)	lift (33%), doesn't know (20%)
	Lift	1	doesn't know (63%)	doesn't know (23%), camera

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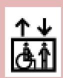
Pictograms	Concepts		Interpretation of pictograms not recognized: Adults	Interpretation of pictograms not recognized: Children
				(16%), car running (13%), mobile phone (13%)
		2	/	toilets (47%)
	Scale		/	doesn't know (17%), line (17%)
	You are here	1	doesn't know	doesn't know
		2	doesn't know (53%), point of interest (15%)	doesn't know (28%), circle (9%), roundabout (9%), target (9%), forbidden (9%)
		3	doesn't know (22%), target (16%)	target (30%), doesn't know (13%), point and circle (10%)

We only accepted precise answers. For example, the interpretation "eat and drink" is too general and can refer to similar concepts such as cafeteria and restaurant. There is a conceptual difference between these two notions. A cafeteria suggests a quick meal, whereas a restaurant implies a longer one. Adults' misinterpretations are often "doesn't know" contrary to children who tried to find an interpretation to all pictograms. In the latter case, interpretations are often descriptive and linked to children experience (school, environment).

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Discussion

The majority of the pictograms initially intended for blind users were not understood by sighted users; in particular, pictograms that are blind-oriented (i.e., designed only for blind) and not figurative, for example, the "reception" or "stairs" pictograms (Table 2). In contrast, we know that these two pictograms are easily and quickly recognized by blind people when integrated into an orientation map. For sighted people, the pictogram "Reception" meant a low WIFI signal. These results suggest that, if we take into account the needs and the perceptions of blind users only, pictograms may not be comprehensible for sighted people.

Children understood the most figurative pictograms such as "restaurant" (knife, fork, spoon/knife and fork). Their low abstraction capacity may explain some of their answers; in fact, children's answers are descriptive. For example, for the signifier 2 of "cafeteria", children said "breakfast" or "eat and drink". Some misinterpretation can also be explained by the similarity between several signifiers, for example for the signifier "lift", many children answered "toilets" because of the two persons side by side on the pictogram.

Several methodological limitations appeared in this study. For example, presenting several alternative pictograms for a single signified concept proved inappropriate with children, who strived to provide a different answer to each design. Besides, pictograms were evaluated out of context and were only graphical. Results may have been different with pictograms inserted in an orientation map, and interpretation may be partly guided by contextual cues. However, our objective was to examine their meaning in absolute terms, without any context. Complementary evaluation *in situ* should be conducted, and the visuotactile (instead of purely graphical) form of pictograms may also influence the interpretation, even for adults.

Colour sometimes proved to influence participants' answers. For example, the concept "stairs", represented by a red gradient once triggered the answer "this pictogram indicates temperature" whereas stairs represented by a black gradient was once interpreted as "this pictogram is a barcode label". To better inform the potential influence of colour on pictogram interpretation, we conducted Study 2 with a subset of pictograms.

Study 2

This study aimed to analyze the impact of colours on the understanding of pictograms by adult sighted users.

Methodology

Participants

Forty-five volunteers (age M = 30,1; min = 19; max = 61; SD = 17) participated in this study.

Material

We selected six pictograms (access, toilets, stairs, information point, you are here and lift) displayed all of them in four colours (black, red, blue and green (RGB colours); Figure 2).

Pictograms were:

- Access represented by a triangle pointing to the right
- Toilets represented by a person in a wheelchair, a man and a woman, one next to the other separated by a vertical line
- Stairs represented by four verticals lines next to each other, lines are less and less thick
- Information point reprenset by the letter "I" in a square
- You are here represented by a target

- Lift represented by a person in a wheelchair to the left of a person standing. They are in a rectagle with two arrows above (on the left: an arrow pointing upwards; on the right an arrow pointing downwards

This resulted in a set of 24 pictograms which were mixed and distributed into four questionnaires, each of which containing only one version of each pictogram.

Figure 2. Pictograms used for the study 2 (from left to right: access, lift, stairs, information point, you are here, toilets) and displayed in the four target colours (black, blue, green and red).

Procedure

During short interviews, the participants were shown the 6 pictograms in turn and asked to give a meaning to each one, in their own words.

Data collection

Spontaneous answers were coded 1 when the colour proved to have influenced the answer or 0 when there was no colour impact. For example, when participants answered “toilets not in use” when the “toilets” pictogram was represented in red, we considered that the colour had an influence.

Results

We observe a low colour impact on the percentage of the answers (Table 4).

Table 4. Percentage of colour impact on the interpretation of each pictogram.

Pictograms	Colours			
	Black	**Red**	**Green**	**Blue**
You are here	0%	0%	7%	0%
Toilets	0%	86%	0%	0%
Lift	0%	0%	2%	0%
Stairs	0%	57%	36%	0%
Access	0%	0%	0%	0%
Information point	0%	0%	29%	0%

Red and green colours added information to several pictogram's interpretation, in particular Toilets, Stairs and Information point. For example, when stairs were displayed in red, some participants said "banned stairs", when toilets were red some of them answered "busy toilets" or interpreted the colour as "interdiction". Conversely, green meant "open", "accessible" or "permission". However, it should be noted that displaying the "you are here" pictogram in red did not alter its meaning – this suggests that it remains possible to use red for this pictogram to attract users' attention at first sight.

In contrast, black and blue never influenced pictogram interpretation.

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Discussion

For the set of new pictograms to be created, pictograms can be displayed in black or blue. When relevant, red can be used for interdiction or danger and green for permission. These results are in line with those of the literature on warning pictograms in which red, orange and yellow colours represent “danger” (Lin, Chang, Liu, 2015). This study was nonetheless useful to confirm that black and blue colours are equivalent and do not interfere with pictogram meaning. We also retain that displaying the “you are here” pictogram in red may be possible to direct sighted users’ attention without altering the meaning of the pictogram.

Study 3

Following Study 1 results, it appeared necessary to redesign several pictograms of our initial set. From a methodological viewpoint, we may mention that our initial top-down approach, drawing on blind users’ special needs to design universal pictograms, proved insufficient. We chose to complement the process with a series of creative workshops focusing on ideas and representations of 3 categories of users, namely sighted adults, adults with visual disability, and sighted children. Study 3, therefore, implements a bottom-up instead of a top-down approach, and relies on participatory methods instead of expert methods which had given rise to the first set of pictograms.

The participatory approach to pictogram design is original in itself, in particular with children and blind users. We chose this method as it seemed the most likely to produce the most cognitive activity of participants with no guidance from expert designers, and highlight similarities and differences between blind and sighted adults as well as sighted children. Involving blind participants in creative workshops remains rare and challenging (Brock et al., 2016; Hendricks et al., 2015).

Methodology

Participants

Four creative workshops were conducted in France: a first adult group (n = 6, mean age = 30 years, min = 26, max = 43, SD = 6,46), a second adult group (n = 16, mean age = 23 years, min = 21, max = 31, SD = 2,50), a children group (n = 6, mean age = 13 years, min =11, max = 15, SD = 2,06) and a group of people with visual impairments (n = 7, mean age = 58 years, min = 48, max = 66, SD = 6,52) in which 4 participants were visually impaired and 3 were blind.

Procedure

We asked participants to create as many drawings as possible for each target concept. The same material was used in all groups: paper sheets (1 blank sheet per participant and concept), small coloured round stickers (3 by participant and by concept), colour pens and big sheets for shared illustrations (1 per concept).

The creative process (inspired by Wallas, 1926 cited by Lubart et al., 2015) was identical for all groups. Our objective was to have a unique procedure that would be applicable to adults, children and iparticipants with visual disability in terms of comprehension, simplicity and duration. The overall structure of the session followed classical brainstorming steps (Osborn, 1953), namely a diverging step dedicated to a fluent generation of ideas and idea-sharing, and a convergent step to evaluate the creative productions.

Ideas generation started with the facilitator delivering the fundamental rules for idea production: (1) suspend your judgment (no critics, no approvals, no judgment, do not destroy the morale of the group, no evaluation), (2) the wildest imagination is welcome, (3) quantity over quality and (4) freely associate your ideas with each other. These rules remained on the wall throughout the session.

Afterwards, the facilitator presented each concept to be illustrated: the target concept was written on a shared screen (for adults and children groups) and read by the facilitator (for all groups). For each concept, the process was the following:

- **Individual phase** (4 minutes): participants were instructed to draw as many drawings of a concept as possible on a sheet of paper . They could use colours as they wanted. Blind people thought to the graphical representations without drawing, but some of them tried to draw.
- **Collective phase** (2 minutes): after the individual phase, sighted participants (adults and children) gathered around a big sheet to draw the most number of propositions together (Figure 4). They could reproduce their individual propositions but were encouraged to draw shared propositions and to enrich them. For blind participants, the facilitator drew based on the participants' descriptions and discussions.
- **Evaluation phase** (2 minutes): to finish, each participant had to evaluate which production(s) were the most typical for each concept. We used the dot-voting method as it is a common method in design sprint. Each participant was provided, for each concept, three coloured stickers' to distribute on 1 to 3 collective proposals. The criteria for votes was to choose the most typical graphical representations from the collective phase. For blind participants, facilitator attributed stickers to concepts based on the participants' instructions. This phase was rapid to get participants to do the vote as spontaneously as possible.

This process of individual and collective productions and evaluation was repeated for each concept.

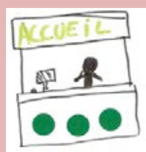
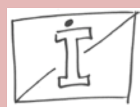
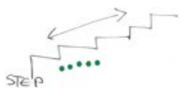
Data collection

We first analyzed qualitatively collective productions. Then, for each concept, we identified the main idea, the percentage of votes assigned and a typical graphical representation. Our selection criteria were the originality of the idea and the possibility to transpose the drawing into a visuotactile pictogram, which requires considering details and dimension.

Results

In total, 2208 graphical representations were proposed, including 1758 individual and 450 collective ones. Table 5 shows the main ideas (pictograms for those which that the most votes), the percentage of coloured stickers assigned and a typically associated image. The concept “scale” was considered secondary and was not submitted to people with visual disability in order to make the session a bit shorter for them.

Table 5. Graphical propositions and percentage of votes for each group and concept.

Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
Reception	 human 50%	 human + « i » 41,7%	 human 50%	 « i » 27,8%
Stairs	 profile stairs+			

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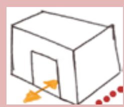
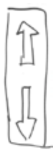
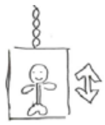
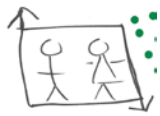
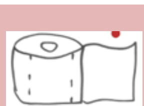
Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
	arrows 61,1%	profile stairs + human 58,3%	profile stairs 66,7%	profile stairs 61,1%
Access	 Arrow + door 38,9%	 Arrow + door 37,5%	 Arrow + door 50%	 Arrow + door 83,3%
Lift	 button+ arrow 33,3 %	 lift shaft+ arrows 75%	 lift shaft +arrow + human 100%	 lift shaft + arrow + human 50%
Toilets	 toilet paper 44,4%	 woman / man 41,7%	 WC 33,3%	 WC + Braille 61,1%

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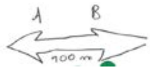
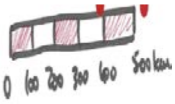
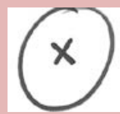
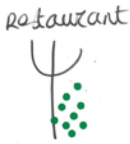
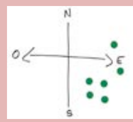
Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
Scale	 ruler 44,4 %	 ruler 70,8	 Ruler 50%	/
You are here	 target 77,8%	 target 91,6%	 target 50%	 target 72,2%
Restaurant	 plate + culteries 22,2%	 culteries 12,5%	 burger 50%	 cutleries 61,1%
Wind rose	 wind rose 94,4%	 wind rose 37,5	 wind rose 33,3%	 wind rose 94,4%

Graphic representations proposed and retained are more figurative than those from our initial set of pictograms. Nevertheless, among the four groups, participants with visual disability' proposals are the least figurative and are coupled with text. These results are in line with those of Study 1, since the pictograms that had not been recognized by sighted participants were the least figurative ones (and the most effective tactilely).

For each concept, our observations are:

- *Reception/information point*: in adults and children representations, there was a human, whereas in people with visual disability representation the letter "i" for "information point" was used. We decided to keep the letter "i" because it is the only proposal compatible with transposability criteria and is one of the few pictograms to be standardized (ISO 7001, 2007). It was also well recognized by adults (study 1). The main limitation of this proposal is that the corresponding pictogram was not understood by children (study 1).
- *Stairs*: all participants represented profile stairs. This representation seems a perfect alternative to stairs seen from the above, which was not recognized in Study 1.
- *Access*: All groups proposed an arrow through a door. We retained this idea but removed the perspective used by Group 2 of adults and children. Arrows alone were not recognized in study 1, and study 3 shows the importance of the context: the door gives direction to the arrow.
- *Lift*: up and down arrows are present in all groups' representations. Children and people with visual disability added humans to the abstract arrows. We decided to keep arrows because, in study 1, children confused "lift" and "toilets" when lift included humans. Moreover, arrows are tactilely more compatible with transposability criteria.

- *Toilet*: adults proposed figurative representations, whereas children and people with visual disability proposed an arbitrary one (WC); we kept the latter representation.
- *Scale*: all groups proposed a graduated scale. We retained the idea to display a segment and add numbers in black and Braille above it.
- *You are here*: the notion of “target” arose in all 4 groups, therefore we decided to propose a target pictogram, assuming that adding volume would further help users understand that it means “you are here”.
- *Restaurant*: adults and people with visual disability proposed cutleries (knife and fork) to illustrate this concept, which is similar to one of Study 1 pictogram that was well understood by both adults and children. We decided to keep the knife and the fork.
- *Wind rose*: all groups proposed a wind rose to illustrate the concept. This result confirms those of Study 1. We retained the wind rose with the indication of North.

Another observation is that participants mostly used the black colour to draw while markers of all colours were available to them. This result is also consistent with Study 2 results.

Design of new pictograms

In respect of the first four principles of Universal Design (i.e., equitable use, flexibility in use, simple and intuitive use and perceptible information) and based on the joint results of Studies 1 and 3, we selected for a new set of visuotactile pictograms the ideas that were likely to meet the following criteria: (1) be suitable for the maximum of users (sighted and visually-impaired adults, sighted children) and (2) comply with transposability criteria (dimension, perspective, simplicity and discriminability).

To facilitate the understanding of pictograms by users, we chose two manufacturing methods to display them. Indeed, following our experience, some pictograms are landmarks: to structure space, so they were manufactured by 3D printing (pictograms in volume), and pictograms judged as secondary were printed through UV injection (pictograms in 2D $^{1/2}$). 3D printing produces pictograms that measure up to 6 mm of height, and UV injection produces pictograms at a maximum height of 2 mm.

Pictograms for 3D printing

Pictograms manufactured in 3D printing (Figure 3) were:

- you are here represented by a target in red,
- reception (information point) represented by the letter “I” in black on white background surrounded by a black circle,
- stairs represented by three stair steps,
- access represented by an arrow pointing to the right,
- toilets represented by the letters “WC” in black on whithe background,
- lift represented by two arrows one below the other.One from the top point up and one from the bottom point down.

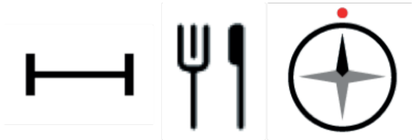
Figure 3. 3D printing’s pictograms, left to right: you are here, reception (information point), stairs, access, toilets, and lift.

Pictograms for UV injection

Pictograms manufactured in UV injection (Figure 4) were:

- scale represented by a segment,
- restaurant representd by a fork and a knife,
- wind rose represented by a wind rose with the indication of North.

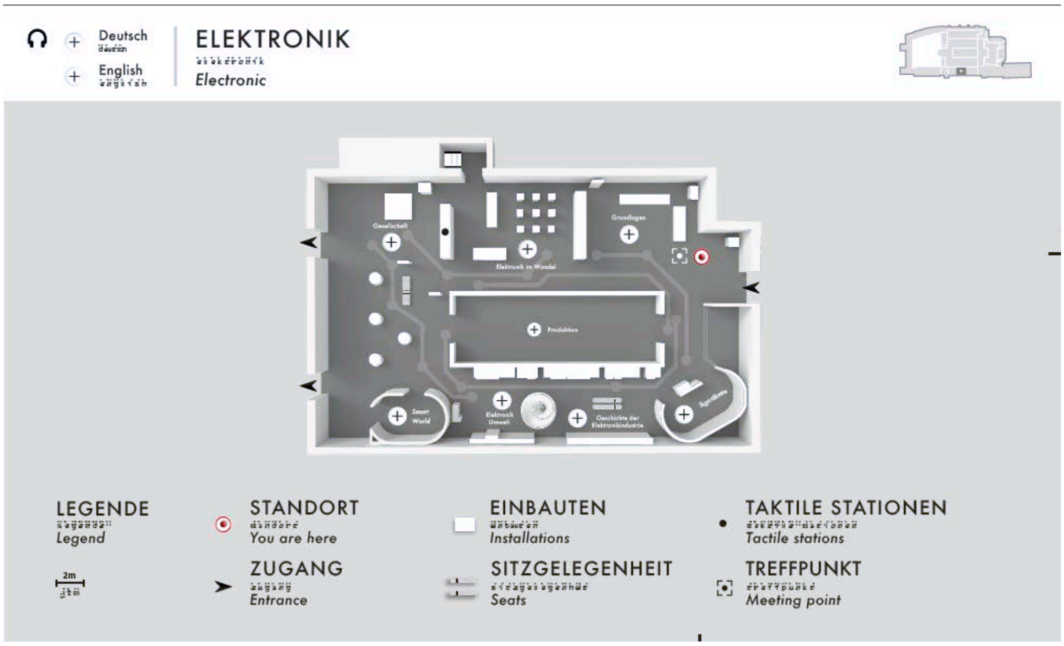
Figure 4. UV injection's pictograms, left to right: scale, restaurant and wind rose.



Integration into a test orientation map

Some of these new pictograms (you are here, stairs, scale, and access) were integrated into a project in Germany with the *Deutsches Museum* (Figure 5) to test their efficiency. The aim was to design orientation maps for each space of the Museum. These maps are visuotactile and include audio, to give information about the content of the exhibition rooms.

Figure 5. New pictograms tested at the Deutsches Museum (the orientation map is rectangle. The title is at the top left with the audio button; the room plan is at the center wit the legend below. The text is in black and Braille).



The orientation map was tested with both sighted and visually-impaired German adults in the Museum. Participants with visual disability (n=20) were mainly born blind, and they were between 50 and 60 years old. Researchers did an unstructured open observation to collect data. Each participant explored alone the orientation map for 15 minutes. Participants put the audio headset and listened to the instructions while they explored the orientation map with their fingers. Participants were guided by the audio information to explore the orientation map. Results of the user tests showed that all pictograms inserted in the map were recognized and understood by sighted and visually-impaired participants. We nonetheless observed several limitations related to the display of pictograms in volume. First of all, when pictograms are printed in high volume, there is no more hierarchy in the information. However, this process is fundamental to enable blind users to understand the most important information first (Boisadan et al., 2016). In particular, the “you are here” pictogram should be the first one to be identified by users because it enables them to structure their mental representation of space and locate themselves in the environment. Nevertheless, the new 3D pictograms representing stairs is higher than the “you are here” pictogram was identified in first. Therefore, new adjustments should be found to optimize the use of volume to foster spatial cognition for blind users.

Conclusion and perspectives

This research aimed to design universal visuotactile pictograms, which still represents a challenge faced by the society as a whole (to allow social participation of all, including people with disabilities) and by many companies and institutions (to provide accessible orientation maps to their customers and visitors). The first main challenge is the absence of standardization for graphical pictograms to be used in orientation maps. Secondly, should such standards exist, they may not be designed to comply with transposability criteria and be used as visuotactile pictograms. Guidelines for tactile information design remain very limited (ETSI, 2002). In this context, the present research provides two main contributions, namely a methodological one and a practical one (sets of pictograms).

The methodological contribution concerns the process of designing universal products. In the present research, we had the opportunity to test two approaches (Plos et al., 2012), a top-down adaptive one, and a bottom-up proactive one, and our results clearly support the latter. More specifically, the first set of visuotactile pictograms evaluated in Study 1 were designed by experts to meet the special needs of blind users, in order to test the possibility of extending their use to the general population. This top-down process appeared insufficient since most of these pictograms were not recognized by sighted users. Orientation maps with such pictograms cannot be universal. To redesign universal visuotactile pictograms, we conducted creativity workshops (study 3) with sighted adults, sighted children and adults with visual disability. Our objective was to find shared signifiers, also considering the mental representation of the three categories of users, which corresponds to a bottom-up approach. In our specific case, this process proved more effective. While the top-down approach had led to pictograms that were too specific, the bottom-up approach enabled us to consider cognitive abilities, needs and expectations of different target groups in pictogram design and meet their requirements.

The practical contribution corresponds to the series of pictograms used in our three studies. In this respect, both those which were validated and those which were not may be of interest to practitioners and sign makers. Pictograms that were not recognized in Study 1 may help practitioners question their choices and avoid some design mistakes. For example, it was particularly interesting to observe confusions between “lift” and “toilets” pictograms in children’s answers. Study 2 addressed the sub-question of the influence of colour on pictogram interpretation. The expected effects of red and green colours were confirmed by the results, but this study also highlighted subtler differential effects of colour as a function of the pictogram. For example, the red colour massively influenced some interpretations (e.g., the “Toilets” pictogram) but did not alter other ones (e.g., “You are here” or “Lift” pictograms). These results would need to be consolidated and replicated on larger and more diverse samples of populations, including various cultural backgrounds. However, they may nonetheless provide design insights to sign makers. Finally, the creativity workshops conducted with adults, children and participants with visual disability also highlighted original results, for example, that mental representations of orientation concepts are partly shared by these three categories of users. More research is still necessary to refine our pictograms, but Study 3 results tend to suggest that the general purpose of designing universal visuotactile pictograms may be achievable. Some challenges remain to be addressed, such as the sometimes antagonist specifications arising from children, who tend to prefer figurative pictograms, and blind users, who may prefer abstract or arbitrary representations.

We observed three methodological limitations of this research. The main limitation of this series of studies is the lack of cultural variability we were able to account for. The three studies were conducted in France, which surely may have influenced the results. Although the final test of the pictograms was conducted in Germany, we are aware of the magnitude of the task ahead to test and refine our pictograms based on feedback and ideas of people (both sighted and visually impaired) from all around the world.

The second limitation concerns study and the process to determine if interpretations of pictograms by participants are correct or incorrect. It was a subjective evaluation by ourselves. In future research, we will use three “judges” who will blindly assess the interpretations. Judges will come from various contexts (for example sign makers or researcher) and/or different culture.

Finally, the last limitation is about the dot voting process used in study 3. We asked participants to choose the most typical representations of each concept. We did not stop participants voting for their own-drawing or the most attractive drawing and not for the most common. In addition, various practitioners (for example see the article of Anderson, 2019) have raised some limits of this method such as familiarity bias, influence by others, or vote-splitting. Similar to the previous limitation, we could submit collective propositions to external judges (for example sighted and blind from France and others countries) and ask them to evaluate proposition through different criteria such as the most original, universal, or the most representative.

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UNIVERSAL DESIGN: FROM DESIGN PHILOSOPHY TO APPLIED SCIENCE

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Abstract: Universal Design (UD) philosophy is inspired by the social responsibility that no discrimination is present in the use of the built environment. During recent decades UD philosophy led to a systematic development of design guidelines for architectural and urban projects aimed at rendering the built environment accessible to all. In Malta, such guidelines are endorsed by central and local government entities and non-governmental organizations and they are covered by legislation which is actively enforced. Moreover, the law stipulates that the planning regulator makes it mandatory that a given development permission complies with these guidelines. This ensures that no barriers can hinder the usage of a given development. The objective of this paper is to demonstrate that UD is not only a legal requisite emerging from a socially sensitive design philosophy and grounded in official design standards that ensure legal compliance, but an applied science aimed at ensuring mobility for all. Using a case study from this European Union Member State, this paper argues that setting the focus on technical specifications relating to access for all falls short of addressing the inherent interdependencies; consequently, it does not tackle UD issues. UD goes beyond the prescriptive requirement established by law and underpins a performance-based design, thereby intrinsically enhancing the quality of any given element, whether a space or a product. UD is an applied scientific discipline; it is a multifaceted, interdisciplinary branch of learning. It involves the application of current

formal scientific knowledge to pragmatic scenarios in order to attain contextual specific solutions. UD is not just an applied design philosophy; it is an applied science integrating anthropometrics, medicine and design; it is universal design science.

Keywords: Universal design, universal design science, design for all, inclusive design, accessibility, heritage design, floating pontoon, Malta.

Introduction

Terminology

A widely used working definition of the term Universal Design (UD) adopted by the Committee on the Rehabilitation and Integration of People with disabilities (CD-P-RR) (Ginnerup, 2009) recommended the endorsement of Resolution ResAP(2007)3 by all Member States of the European Union. This resolution (Council of Europe, 2007) states:

“Universal Design is a strategy which aims to make the design and composition of different environments, products, communication, information technology and services accessible and understandable to, as well as usable by, everyone, to the greatest extent in the most independent and natural manner possible, preferably without the need for adaptation or specialized solutions.”

This resolution builds upon Council of Europe Resolution ResAP(2001)1 (Council of Europe, 2001), known as the ‘Tomar Resolution’ (Council of Europe, 2007), which was adopted in 2001. Resolution ResAP(2007)3 is echoed in the introductory paragraph of the executive summary of the report drawn up by Søren Ginnerup in co-operation with the Committee of Experts on Universal Design (Ginnerup, 2009). The term UD is used in this report as a broader label to include other terms used with respect to access for all design, namely, ‘design for all’, ‘integral accessibility’, ‘accessible design', 'inclusive design', 'barrier-free design', 'transgenerational design' and 'accessibility for all'. Likewise, the term UD was used in this article.

Accessible design need not be UD. "At a basic level, accessibility operates on an 'access' scale (from not difficult to access through degrees of difficulty to impossible to access, with the defined group including everyone). UD has several roots, including usability, which tends to operate on a 'use' scale (from easy to hard to use by a collective group that includes as many people as possible within this group)" (Erlandson, Enderle, & Winters, 2006).

A fundamental principle of UD is equity. One should not differentiate between users; any given element should be appealing and usable by all. A ramp is required for wheelchair access and individuals with restricted mobility, but consideration is to be given to its aesthetic quality and/or stigmatizing effect (Erlandson, Enderle, & Winters, 2006). Christopher Day, an architect by profession and author of several seminal publications with a foreword by H.R.H. The Prince of Wales, published an inspirational humorous book about access for all soon after he was diagnosed with Motor Neurone Disease, one of the most severe degenerative diseases (Day, 2007). This publication is a critique of his personal experience of accessibility in cities, on mode of transport and access for all ranging from walking sticks to wheelchairs, an experience which he termed "non-accessible accessibility".

Within the context of UD, and other terms falling under its umbrella as noted above, official bodies such as the Council of Europe, particularly the cited resolutions, repeatedly referred to people with disabilities. Although describing such individuals as disabled was the prevalent established discourse, the *Regional Socio-Economic Plan for the South of Malta*, published years before Council of Europe Resolution ResAP(2001)1, makes use of the term 'people with special needs' (Planning Council, 1998). The author, then the Chairperson of the Planning Council responsible for initiating research as the basis for the drafting and completion of this publication, considered references and allusions to people as being disabled and/or handicapped as insensitive, humiliating and degrading. In fact, the

Planning Council's over-reaching philosophy was that such people were individuals with diverse abilities rather than disabilities.

Historical Backdrop

Since the European Convention for the Protection of Human Rights and Fundamental Freedoms, which was drafted in 1950 and came into effect in 1953, there is a growing awareness of UD supported by legislation and guidelines both within European Union Member States and also in other countries. The major milestones in the development of UD were tabulated in a publication of the Council of Europe issued a decade ago (Ginnerup, 2009). These included landmark conventions, declarations and resolutions, international events, national legislation, action plans, research and other initiatives. All are grounded in, and implicitly reinforce, the conviction that people with permanent and temporary special needs should not be discriminated against since they are entitled to enjoy their full rights and freedoms as the rest of society. Although qualitative research undertaken by Ginnerup (2009) concluded that most of the above mentioned events and resolutions had been incorporated into national, regional and local initiatives, UD in practice is still read as a mere application of technical specifications imposed by enacted legislation. Therefore, it needs to be complied with for given design proposals.

The principles of UD were developed at the Centre for Universal Design at North Carolina State University (Table 1) (Connel et al., 1997) although the first pioneering publication was by Goldsmith (1963) followed by others, such as Farrant and Subiotto (1969), and Boswell and Wingrove (1974). This centre, formerly known as the Center for Accessible Housing, was established in 1989 by Ronald Mace together with North Carolina State University, his alma mater. Wheelchair user since the age of 9 after contracted polio, Mace was instrumental in getting the accessibility-focused building code mandatory in North Carolina in 1973, the first in the United States. Some of his key publications include Mace (1980) and Barrier Free Environments Incorporated (1991), the latter being a consulting firm which

Mace directed. Together with Story, Mace had co-edited an issue on UD for the authoritative academic journal Assistive Technology (Story & Mace, 1998). In this issue he published a seminal, comprehensive paper on UD in housing (Mace, 1998) whereby he argued that UD goes beyond the threshold for accessible design and do lead to homes that are usable and marketable.

Table 1. The Principles of Universal Design (Connel et al., 1997)

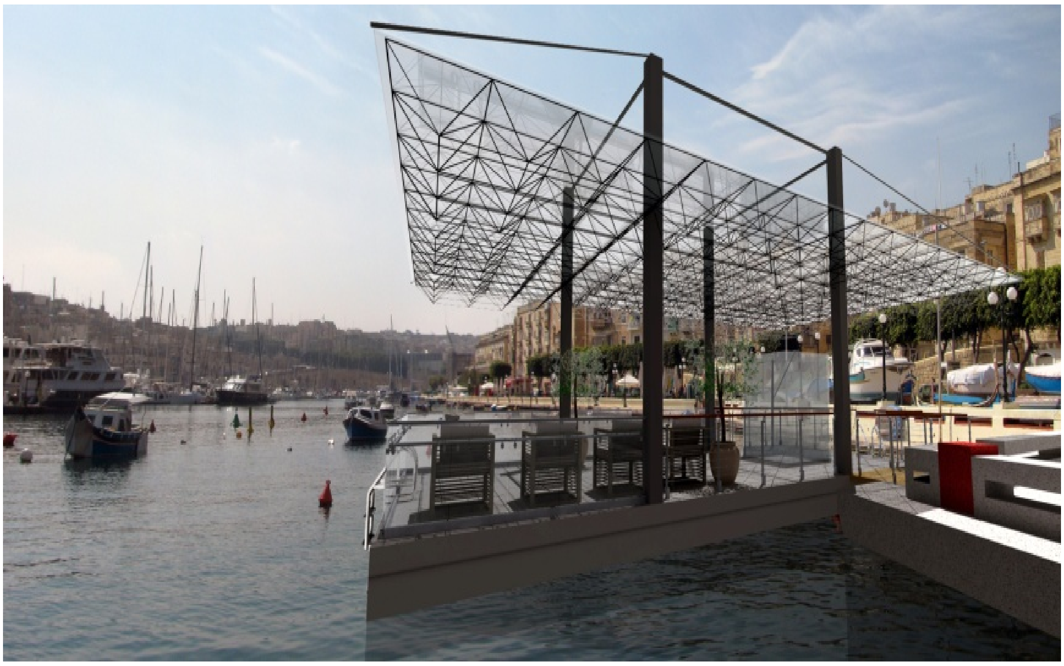
No.	Design Principle	Objective
1	Equitable Use	The design is useful and marketable for people with diverse abilities.
2	Flexibility in Use	The design accommodates a wide range of individual preferences and abilities.
3	Simple and Intuitive Use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
4	Perceptible Information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
5	Tolerance for Error	The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6	Low Physical Effort	The design can be used efficiently and comfortably and with a minimum of fatigue.
7	Size and Space for Approach and Use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

The British Standards Institution issued its first code of practice addressing accessibility for disabled people, namely the British Standard Code of Practice CP96 (BS CP 96, 1967) in 1967. Despite these principles, which are essentially guidelines, the 1999 project of the Royal Institute of British Architects culminating with the publication of the first handbook on design indicators for special needs by Harker and King (2002), and other seminal publications notably by Imrie and Hall (2001), ease of mobility and full accessibility are still an issue around and within buildings (Carvalho de Souza & Duarte de Oliveira Post, 2016; Mustaquim, 2015).

Aim of the study

This article presents a case study which illustrates UD beyond merely conceptual design philosophy. It involves a design proposal within a sensitive cultural and maritime heritage context, namely a floating sea terminal and other pontoons for the traditional 'dgħajsa tal-pass' (translated as 'passage boat' in the Laws of Malta, 2009), a passenger-carrying small boat, in the Grand Harbour, Malta (Figure 1).

Figure 1. Artistic Impression of the proposed floating Sea Terminus which illustrates UD beyond merely conceptual design philosophy. Source: Lino Bianco and Associates (2011)



This case study is not merely an investigation regarding accessibility to sea craft from floating structures for persons with disability. It can be considered as offering a unique solution which symbiotically merges an architectural concept with access for all requirements not just from a prescriptive adhesion at law but as an applied science. It was included in the Grand Harbour Network Initiative, part of the SeaToLand project of the Foundation Temi Zammit. The architectural brief was to develop designs to maintain and sustain the maritime traditional legacy associated with the dgħajsa tal-pass, the traditional water taxi synonymous with this geographical region (Muscat, 1991; Muscat, 1999; Muscat, 2009).

Methodology

Review

The focus of the architectural brief was to create a special assistive technological product design which is inclusive and can be easily replicated in aquatic environments. This study is based on official development planning policies and design guidelines together with consultations with the interested parties involved, both governmental and non-governmental agencies. Thus, the designs developed were:

- complementary to the geocultural and maritime heritage legacy of the Grand Harbour region,
- compliant with approved policies included in the *Structure Plan of the Maltese Islands* (Planning Services Division, 1990) and the relative local plan (Planning Authority, 2002);
- in consultation with the relevant stakeholders, namely, the barklori (the boatsmen), the Local Councils of the various cities within the Cottonera Region, and government authorities and agencies; and
- compliant with the *Access for All Design Guidelines* (AADG) (Spiteri, 2011).

The anthropometric dimensions for the proposed sea terminus were obtained from:

- AADG,
- interviews with the key players including

    - Lawrence Ancilleri from the Koperattiva tal-Barklori (Boatsmen's Cooperative),
    - Ahar family, notably Walter then secretary of the Koperattiva, who has been associated with the operations of water taxis for several decades, and
    - Abela family, notably Alfred,

- technical measurements and observations of water taxis in use.

Access for All Design Guidelines (AADG)

The AADG (Spiteri, 2011) is a practical, concise publication and provides all-round information on UD. It is an enforceable legal document as it is the official publication of the National Commission Persons with Disability (KNPD), Malta, a commission legally established through Act I of 2000 entitled 'Equal Opportunities (Persons with Disability) Act' (Laws of Malta, 2000). Unlike the case of the United States whereby accessible design has a specific legal definition and Access Board accessibility guidelines specifically cover architecture, transportation and communication as related to electronic and information technologies (Erlandson, Enderle, & Winters, 2006), the Maltese framework is less specific. Although there are aspects which need to be addressed, these guidelines are a document aimed at maximizing accessibility through architecture and urban design specifications. Compliance with the access for all guidelines is legally binding, and they are consciously integrated by practising architects and civil engineers in their architectural and infrastructural projects. Students reading courses in the built environment studies at undergraduate level at the University of Malta are introduced to AADG guidelines through design workshops whereby they have to apply and integrate them into their design coursework. Such architectural education in UD falls short of the model proposed by Sungar Ergenoglu (2015) which proposes six teaching modules: the first four at undergraduate level (UL) while the last two at postgraduate level (PL). The former introduces students to the background and the significance of UD concluding with a case study whilst the last two, a continuation of the former, aim to review and share best practices (Table 2).

Table 2. Teaching modules for UD teaching in architectural education (after Sungar Ergenoglu, 2015)

Module	Level	Title	Aim
1	UG	Pre-evaluation	Introduction to the understanding of UD
2	UG	Basic disability and diversity information and case study	From a theoretical background and awareness building to disability issues
3	UG	The relationship between the UD concept and architectural design	Introduction to UD concepts, assistive technologies, anthropometrical dimensions and physical barriers in built projects
4	UG	Case study	Identifying UD issues and resolving them
5	PG	Review	Review modules 1 to 4 and introduction to best practices
6	PG	Searching and sharing (being up-to-date)	Searching and sharing best practices and trends in UD issues and generation of innovative ideas

Case Study

The Context

The Maltese archipelago, the smallest-in-size and most densely populated Member State of the European Union, is located in the middle of the Mediterranean Sea, 93 km south of Sicily and 333 km north of Libya. It consists of three major islands: the largest and the seat of government is Malta with Valletta as its Capital. Malta has several natural harbours; the largest being the Port of Valletta also known as the Grand Harbour (Figure 2).

Figure 2. The Maltese Islands. The location of the Grand Harbour and the main cities within the area relevant to the Grand Harbour Network Initiative is indicated in red (1: Valletta, 2: Isla, 3: Birgu, 4: Bormla and 5: Kalkara). Baseline photo: Google Earth

Utilised since the dawn of prehistory, this harbour was the operating base of the Hospitaller Order of St John which was essentially a naval power. The maritime heritage associated with this harbour includes the historical timber rowing boat, known as dgħajsa tal-pass, which commuted within the harbour and cut across its creeks, ferrying passengers and small luggage to and from ships (Muscat, 1991; Muscat, 1999). At the turn of the twentieth century about 2,000 such crafts operated in the Grand Harbour (Muscat, 1991). The

Vilhena Code and the De Rohan Code issued in 1724 and in 1784 respectively, specifically refer to the use of this boat within the harbour (Muscat, 1991). The latest subsidiary legislation in Malta still defines "passage boat" as "the traditional Maltese dgħajsa licensed for the conveyance of … passengers within the Grand Harbour …" (Laws of Malta, 2009). The dgħajsa tal-pass, the Maltese version of the Venetian gondola and theme of a 20-minute film directed by Narcy Calamatta (Calamatta, 2013), survived for centuries although the original design was modified particularly during British rule (Muscat, 1991). The Foundation Temi Zammit, chaired by the former rector of the University of Malta and Malta's leading philosopher Peter Serracino Inglott, in 2011 had launched the Grand Harbour Network Initiative in order to sustain this mode of transport and the heritage associated with it.

Grand Harbour Network Initiative

The ultimate aim of the Grand Harbour Network Initiative was the sustainable safeguard of the maritime culture synonymous with the Grand Harbour region. Several tangible and intangible aspects were identified with respect to the legacy associated with the dgħajsa tal-pass (Lino Bianco & Associates, 2011), namely, the traditional trades involved in the building and maintenance of such boats and the skills of their boatsmen, the 'barklori' (the plural of the Maltese word 'barklor') (Table 3). The barklor traditionally stood facing forward, making use of two oars to propel the dgħajsa tal-pass frontward.

The three tangible aspects identified were: fabric, activity and memory. Fabric conservation relates to the restoration and maintenance of the boat building material, normally white deal (Muscat, 2009), with red pine for frames, floors and planking (Muscat, 1991). A substantial number of the remaining small fleet of circa a dozen crafts, mostly dating to the first decades of the twentieth century, require restoration while others have been damaged beyond repair. The oldest, now restored, is the Palomba which is attributed to the second half of the nineteenth century (Oldest 'dgħajsa', 2014).

These boats have several decorative elements which are worth restoring and conserving for their particular merit. These include the tablet-sculptures representing saints and patrons and the high stem and stern which vary from craft to craft. Activity conservation refers to the revival of the dgħajsa tal-pass as a means of sea transport within the Grand Harbour. Although it is still prevalently used ferrying tourists visiting the Grand Harbour, its use is marginal with locals. Further to this cultural heritage implication, such a mode of transport has logistic and environmental benefits as vehicular traffic in the region, notable from the south to the central part of the island, is substantially significant especially during peak hours. The cultural significance of the dgħajsa tal-pass, in terms of both aesthetics and historic integrity, is the memory which this initiative aimed to conserve.

Table 3. Tangible (1 to 3) and Intangible (4 to 6) Cultural Heritage Characteristics of the Grand Harbour Network Initiative

Cultural Heritage	Conservation Aspects	Characteristics
1	Fabric	Restoration and maintenance of the boat building material
2	Activity	Revive the use of dgħajsa tal-pass as a mode of transport
3	Memory	Cultural significance of the dgħajsa tal-pass
4	Trade	Boat construction skills
5	Skill	Handling skills to propel and manoeuvre manually the dgħajsa tal-pass
6	Identity	The dgħajsa tal-pass was included in the Coat of Arms of Malta; a modified version is used annually in the traditional regattas held on national days

Concerning the intangible aspects, the following were identified: trade, skill and identity. The construction of a dgħajsa requires a high level of craftsmanship (Muscat, 1991). The knowledge and ability to building such timber sea crafts were passed on through generations via master artisans, mostly coming from the Cottonera area, a trade which nowadays approaches extinction. The gradual decline in the construction of the dgħajsa can be traced back to the socio-political and cultural changes precipitated by the rundown of the British services after Malta's Independence in 1964. In fact, the decrease in the number of warships and auxiliary naval vessels in the Grand Harbour rendered the employment prospects of the boatsmen bleak (Muscat, 1991). Permits issued by the Malta Maritime Authority in 2007 for fibreglass replicas or high-speed water taxis exacerbated this trend (Ahar, 2007; Save The dghajsa, 2007). A master craftsman, Joseph Mallia, had called for the revival of the timber boat building tradition some years earlier (Cini, 2003). Furthermore, the barklor as a form of employment was also disappearing. Only a few still retain the skills to steer, maintain and manoeuvre a dgħajsa tal-pass.

All this notwithstanding, the national identity is still strongly associated with this boat. It was included in the Coat of Arms of Malta used from 1975 to 1988. A modified, lighter version of this craft, known as 'dgħajsa tal-midalji' (literally translated as 'boat of medals') is used for the annual Regatta held on Freedom Day (31 March) and Victory Day (8 September) (Serracino, 2010).

To conserve and sustain the tangible and intangible heritage a polycentric approach was adopted to ensure that the initiative will be socio-economically feasible. This was undertaken through the utilization of existing infrastructural networks while ensuring improved sea-to-land intra-connections. Five sites were identified to launch this initiative, each having a distinctive, respective architectural design intervention. The proposed interventions were the following: a sea terminus, a landing/embarkation point, an interactive experience heritage centre, administrative offices and a restoration/maintenance workshop (Table 4).

These interventions are all located at Isla, one of the Three Cities (namely: Birgu, Bormla and Isla) which are collectively referred to as Cottonera, except for the landing place located at the Birgu waterfront facing Kalkara (which served as a prototype for any location within the harbour area) and the restoration/maintenance workshop which underlies the incline of Triq Ix-Xatt Juan B. Azzopardo, Bormla (Figure 3).

Table 4. Design Interventions included in the Grand Harbour Network Initiative

No.	Proposed Interventions	Location in Isla	Design Interventions
1	Sea Terminal	Waterfront along Triq Ix-Xatt Juan B. Azzopardo, Isla	Designed on the proportions of the dgħajsa tal-pass
2	Landing Place	Prototype for any future location	Designed similar to the terminal but to a smaller footprint; it is a prototype for any location along the quays of the Grand Harbour
3	Interactive heritage centre	St Michael's Ditch, Isla	Restoration of a building dating back to the British Period and its conversion into an interactive experience heritage centre
4	Restoration and Maintenance Workshop	Underlying Triq Ix-Xatt Juan B. Azzopardo, Bormla	Restoration of a former H.M. Naval Dockyard store and its conversion into a boat building/maintenance workshop
5	Administrative Offices	60, Triq San Guzepp, Isla, overlooking Isla foreshore	Upgrading of a substandard dwelling and its conversion into offices

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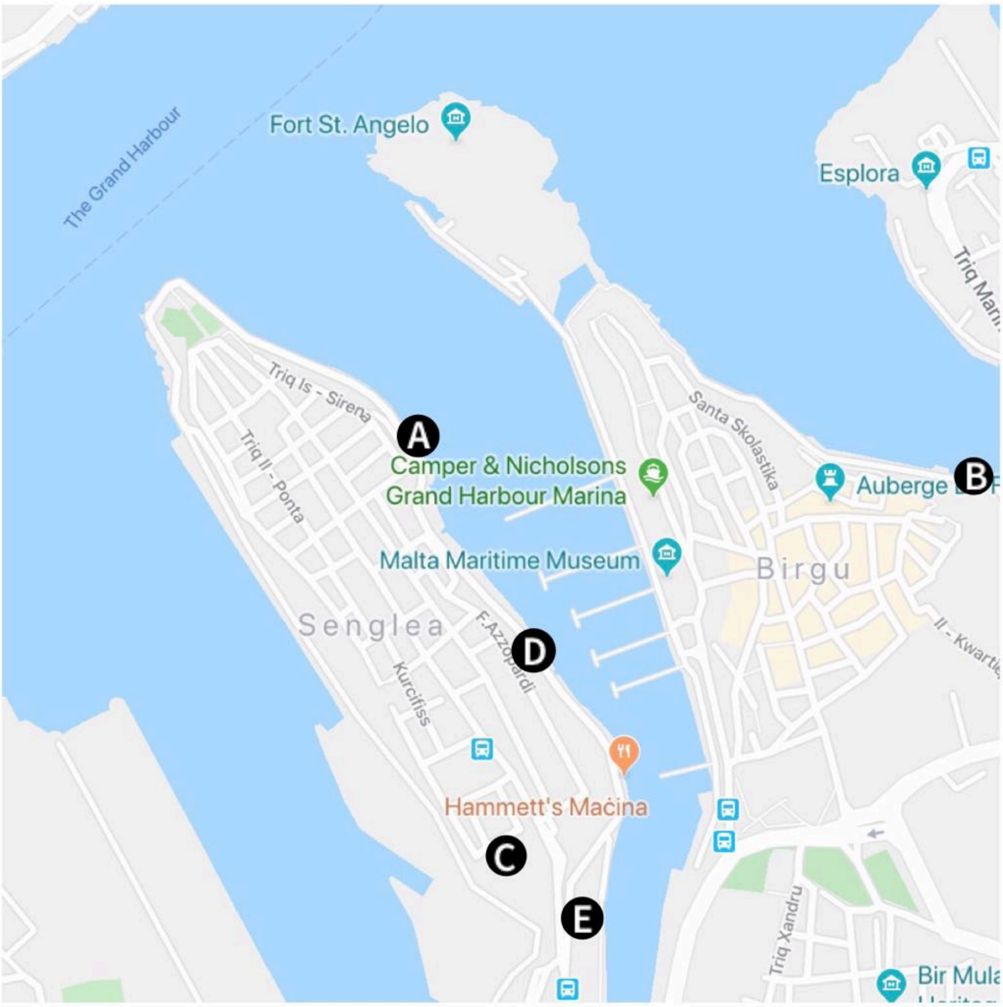
Given the cultural heritage significance of the Grand Harbour region in general, and Isla in particular, two of the key design decisions of this project were adaptability and reversibility. Thus, all proposed interventions respect the historical-aesthetic character of the environs. While the restoration and conservation of built heritage are minimal on the exterior of the building envelopes, the interventions in the interior are, wherever required, the least possible to permit the new adapted use of the space within. The sea terminus, which has a stainless steel space-frame to support the glazed roof, was designed on the geometrical proportions of the dgħajsa tal-pass (Figures 1 and 4). The transparent and reversible nature of the design is sensitive and does not hinder the present views of the Grand Harbour (Figure 5).

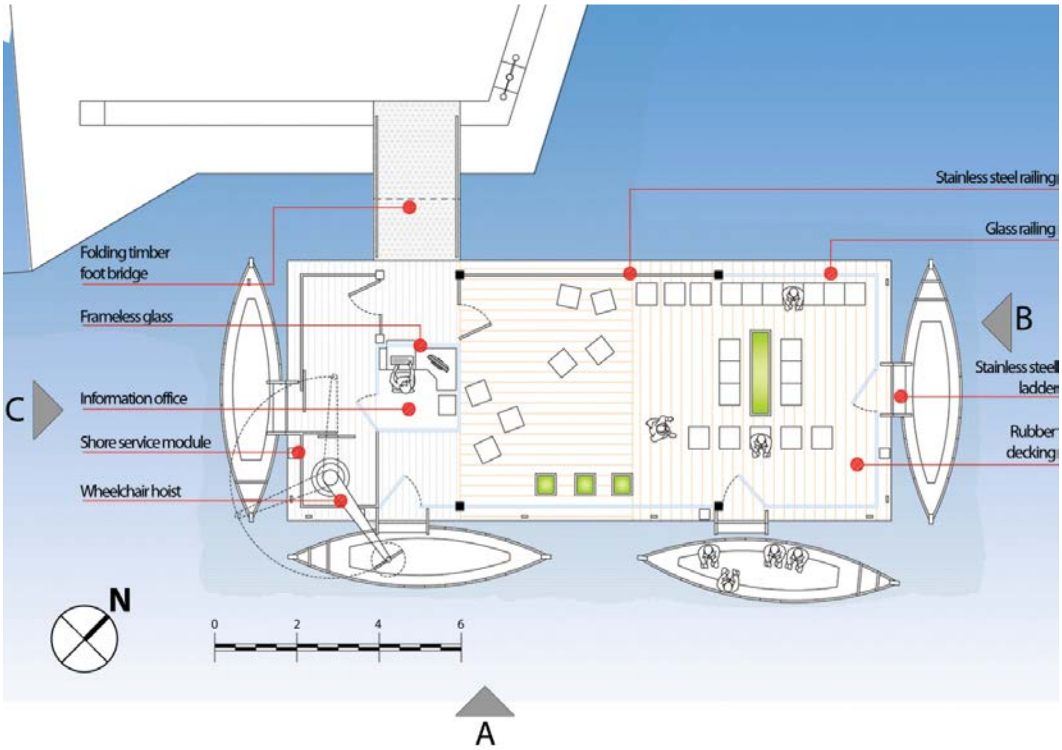
Figure 3. Site plan showing the location of the proposed historical-aesthetic interventions (A: sea terminus, B: landing place; C: interactive heritage experience centre, D: administrative offices and E: a restoration and maintenance workshop). Baseline photo: Google Street View



The landing place, a prototype for other locations within the harbour, is also a floating pontoon designed similar to the sea terminal but on a smaller footprint. Such pontoons are easier to relocate or remove as circumstances dictate, e.g. to accommodate third party projects/interventions/demands.

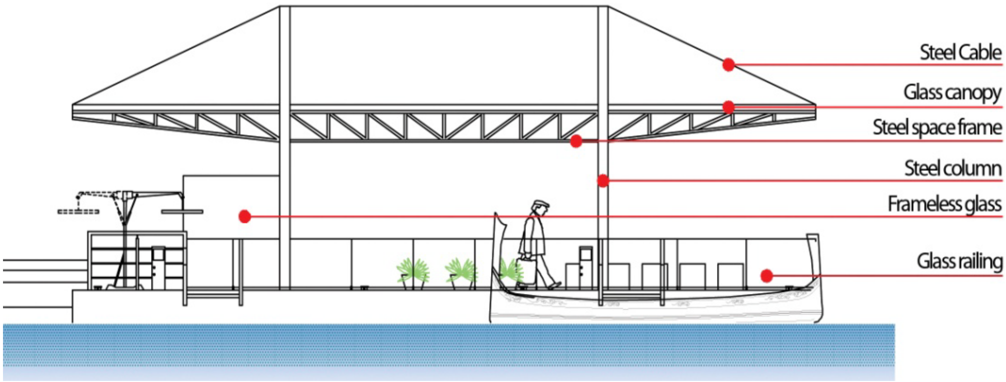
The twentieth-century building dating to the British naval period, located within St Michael's Ditch, was designated as an interactive heritage experience centre.

Figure 4. The geometrical proportions of the plan of the Sea Terminus are based on the dgħajsa tal-pass. Source: Lino Bianco and Associates (2011)

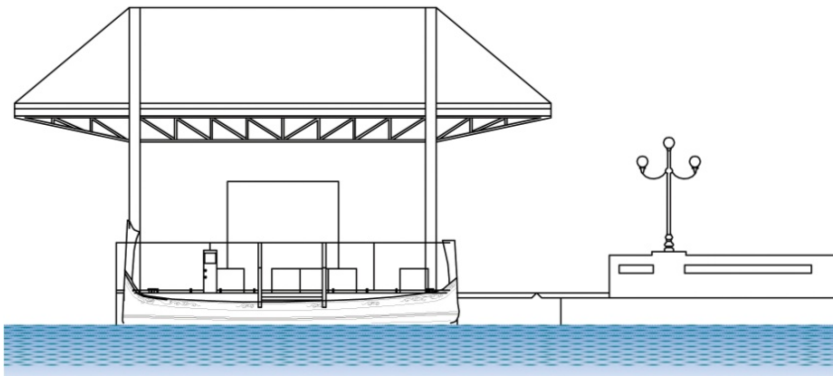


One of the former stores of H.M. Naval Dockyard, facing Birgu waterfront, was selected to be converted into a restoration and maintenance workshop for the dgħajsa tal-pass and could also support the building of such vessels. A substandard residential apartment, accessed from Triq San Guzepp and overlooking the waterfront along Triq Ix-Xatt Juan B. Azzopardo, was projected to be restored and converted into offices housing the management and administrative units of the project.

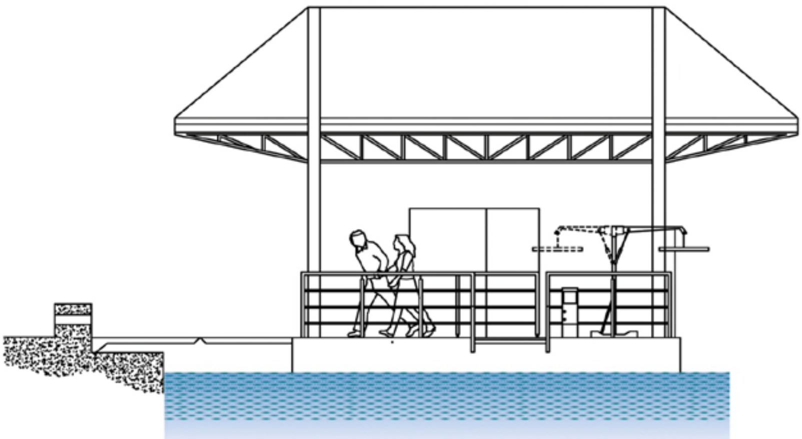
Figure 5. Elevations of Sea Terminus indicated in Figure 4 showing the stainless steel space-frame to support the glazed roof. The transparent and reversible nature of the design is sensitive and does not hinder the present views of the Grand Harbour . Source: Lino Bianco and Associates (2011)



Elevation A



Elevation B



Elevation C

Results

Anthropometric Dimensions

The individuality of a given dgħajsa tal-pass is constituted by its painted parts, typically chosen from an established colour scheme which included green, red, yellow and white. The dimensions of the craft have standard specifications: the length, beam and depth should be 6.3 metres, 1.55 metres and 0.45 metres respectively. With a length of 0.52 metres for each passenger, the carrying capacity of the boat was set at 10 passengers and 2 rowers (Muscat, 1991). These specifications have to be adhered to as any failure to comply with these standards precluded the granting of a licence to operate such a craft by the competent authority (Muscat, 1991).

The technical measurements relating to the craft have been confirmed by the author who had measured some dgħajjes (plural of dgħajsa) propped up on land for maintenance works. The average dimensions and the variations from the standard are tabulated below (Table 5). It is confirmed that strict adherence to the standard has been maintained in the building construction of the crafts studied.

Table 5. Variations between technical measurements and standard specifications for the dgħajsa tal-pass

Parameter	Measurements	Standard	% Variation
Length	6.40 metres	6.30 metres	+ 0.02
Beam	1.53 metres	1.55 metres	- 1.30
Depth	0.46 metres	0.45 metres	+ 0.02

The floating sea terminal is subject to swells. Thus, the pivoted folding timber footbridge (see Figure 4) is adjustable in length to take into account wave action. The maximum permissible gradients of the footbridge vary with the vertical movements of the water, which are given in Table 6. The width of this bridge is 2m, that is over the 1.2m width required for wheelchair users.

Table 6. Permissible gradients to accommodate swells

Swell	Maximum gradient of footbridge	Foldable footbridge length
< 10 cm	1 : 10	< 5 m
< 25 cm	1 : 12	< 6 m
< 50 cm	1 : 16	< 8 m
⩾ 50 m	1 : 20	≥ 10 m; ≤ 12 m

Analysis

The accessibility audit on behalf of the National Commission Persons with Disability was undertaken by Joseph Spiteri, the lead academic and expert in the field of access for all design guidelines in Malta. The drawings for the floating sea terminal, vetted in terms of the AADG, were deemed compliant provided that the comments included in the assessment were addressed (Spiteri, 2012). Table 7 includes the considerations undertaken when auditing the design from AADG perspective.

Discussion

The sea terminal proposed at part of the Grand Harbour Network Initiative, a floating raft for the traditional water taxi, is an essay in anthropometric science applied to a UD compliant floating pontoon. The design philosophy is grounded in the spirit of place, namely the Grand Harbour, one of the largest, heritage-rich, natural occurring harbours in the world. As a traditional passenger boat, the dgħajsa tal-pass is strongly associated with Malta's national identity and with the Grand Harbour in particular, a historical fact acknowledged in contemporary legislation (Laws of Malta, 2009). The tangible and intangible heritage associated with this craft

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factually formed an integral part of the operations within the harbour. The call of the accessibility audit for details of the area around the access to the pontoon (Table 7) is legitimate. UD calls for the holistic planning of the urban infrastructure in the area around the proposed development. For example, kerb heights should comply with the required dimensions, while surfaces should be regular and finished in a non-slip material.

The design of the sea terminal is barrier-free and inclusive, the main notions underlying UD, as people with permanent or temporary special needs can access the dgħajsa tal-pass thus contributing to the integration of such individuals into social life. Furthermore, this design proposal is not merely a conceptual UD philosophy applied to architecture but an actual holistic UD. It is not only congruent with the resolution put forward by the Committee of Ministers (Council of Europe, 2007) whereby it recommended to all its Member States to accept UD as a philosophy and strategy aimed at supporting "full citizenship and independent living" for all including those with special needs in terms of Resolution ResAP (2007)3 but one whereby UD is effectively applied science.

Table 7. Accessibility Audit. Based on: Spiteri (2012)

Location of Access	**Design Considerations**
Around the building	Details (such as kerb heights) concerning the area around the building have not been submitted. Thus conformity, or otherwise, to the AADG could not be ascertained. Any approval of the design is on condition that the areas around the building do conform to the AADG
Into the building	The entrance is indicated as 2100 mm wide and level
Within the building	A wheelchair hoist is indicated in the submitted drawings. Also, the proposed floor material is timber and rubber decking. These materials are approved on condition that the ground is level and smooth.

UD is not a privilege but a right, a right to access at all times a given place and/or space with ease. Persons with physical and cognitive impairments require accessible, usable and safe design. Permanent or temporary disability, the former accounting for circa 15% of the population of the western world (Björk, 2009), is a deficiency in human ability implying that accessibility will be an issue unless one thinks holistically about such a reality. No limitations should be present as they hamper access. Ignoring UD is socio-economically expensive (Björk, 2009). While legislation and guidelines are effective if abided, UD forms an integral part of the basic design concept, thus rendering it an applied science underpinning a product which is socio-economically efficient. A product or design element may be suitable in terms of accessible design guidelines, but unsuitable as it is unsafe. A ramp may comply with the design guidelines in terms of dimensions and gradient but may constitute bad design, effectively hazardous to users if it is facing a street rather than a sidewalk.

The disclaimer included in the audit report for the floating pontoon states that the applicant is responsible for ensuring that the development complies with the AADG and “any approval given herewith does not exonerate the applicant from adhering fully to all the recommendations set in the said guidelines, notwithstanding the contents of this report” (Spiteri. 2012). Nevertheless, the onus of a design within the built environment is on its creators, architects and urban engineers (Ochieng, Onyango, & Wagah, 2017). Enhancing accessibility awareness in society falls within the social responsibility of architects (Sungur Ergenoglu, 2015). An architect and product designer who had worked determinedly for such an objective was Mace, cited above, who had coined the term UD. He was indeed the pioneer for user-friendly, all-inclusive, design environs and head of the firm Barrier Free Environments which had undertaken ground-breaking work in the sphere of accessibility.

Limitations

This case study was assessed and analysed based on the AADG. These guidelines are specific, yet they fail to address the various degrees of capacity and limitations imposed by various active disabilities. For example, while the elderly are placed in the category of adults without disabilities (Kroemer, 2006), they are physically and psychologically undergoing gradual transformations such as a decrease in anthropometric size (Hasiholan, Susilowati, & Satrya, 2019) and cognition (World Health Organisation, 2018).

Conclusion

Design philosophy relating to UD broadly adopts a prescriptive approach whereby the focus is compliance with legislation/s, directive/s and guidelines which may not necessarily meet all the needs of the users (Froyen, 2012; Sanford, 2012). A recent study departed from the prescriptive to a descriptive approach to UD (Mosca et al., 2019b). It focused on methods to inspire architects on official design guidelines through information gathering and advice. Moreover, it proposed criteria to translate design requirements arising from the ultimate users of a given space into design strategies. Citing several studies (Froyen, 2012; Sanford, 2012; Mosca et al., 2019a), Mosca et al. (2019b) argue that “it is performance-based and requires an individual understanding, which is necessary for critically analysing the situation and considering the requirements of a range of individuals with different ability levels”. They further argued that “if the prescriptive approach brings to the fore a mechanical application of codes and norms, the latter allows designers to find a proper solution for their own individual projects”. Adopting a performance-based approach is what UD as an applied science involves. It leads to designs with inclusive environs beyond the prescriptive requirements at law.

The foremost aim of UD is to create spaces, products, technologies and services that are accessible to all without need for modification. The design and layout of such elements impinge on the independence of the users. UD is not merely about compliance with guidelines since there are instances when there are logistical and health hazards associated with particular guidelines-compliant features and designed spaces. Focusing solely on technical specifications falls short of addressing the inherent interdependencies and does not solve UD issues. While design philosophy is effective to ensure that a given project conforms to UD, as an applied science UD intrinsically enhances the quality of an undertaking. It goes beyond finding a design solution to meet design specifications. UD is a multi- and inter-disciplinary branch of learning whereby design guidelines are analysed and applied in the overall design approach; concepts and methods of accessibility are integrated to address particular requirements of users within given social, economic and urban contexts. It involves the application of current formal scientific knowledge to pragmatic scenarios in order to attain an explicit specific solution. It is an applied scientific discipline and not merely an applied design philosophy. It is universal design science applying anthropometrics, medicine and design.

Acknowledgments

The author would like to thank the late Reverend Professor Peter Serracino Inglott, the former Rector of the University of Malta and former Chairman of the Temi Zammit Foundation, and Jesmond Xuereb, the Chief Executive Officer of the same foundation, for their valuable insights. Special thanks go to architect William Bondin and draughtsperson Luana Vella who were an integral part of the design team at Lino Bianco & Associates. Final thanks goes to David Caruana, former consultant of the technical committee on social issues involved in the drafting of the Regional Socio-Economic Plan for the South of Malta (Planning Council, 1998), who provided constructive comments on an early draft of this paper.

Disclosure

Following a bid for the architectural services to develop the Grand Harbour Network Initiative, the designs were entrusted to Lino Bianco & Associates which was set up by author in 1997 to render architecture and environmental planning consultancy.

The Foundation Temi Zammit subsequently applied to the Malta Environment and Planning Authority to obtain planning consent through five development planning applications, one for each proposed intervention. Following the demise of Serracino Inglott the applications were systematically refused planning consent thus rendering the Grand Harbour Network Initiative not eligible for EU funding. Also, in due course, the site for the interactive centre was handed over to a local non-governmental organization unrelated to Foundation Temi Zammit.

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OBJECTIVE EVALUATION OF ENVIRONMENTAL OBSTACLES ENCOUNTERED IN TWO CANADIAN URBAN SETTINGS BY MOBILITY DEVICE USERS

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Abstract: Individuals using ambulation or wheeled assistive technologies encounter obstacles when accessing built environments. Although there are many environmental evaluations allowing the identification of these obstacles, very few take into consideration both outdoor and indoor environments. Since we know little about the environments of individuals with mobility impairments regarding their mobility assistive technologies (MAT) and mobility in general, the aim of the project was to objectively describe environmental obstacles encountered by mobility device users in two Canadian urban settings. Locations to be evaluated were nominated by community dwelling MAT users during focus groups in Quebec City (n=25 participants) and community forums in the Vancouver region (n=30-45). The measure of environmental accessibility (MEA) was used to evaluate the outdoor and indoor identified barriers. Relevant MEA sections were completed based on problems that were noted by MAT users, and non-compliant items were recorded. Nineteen locations (buildings and exterior spaces) in Quebec City and 20 in the Vancouver region were evaluated. Fifteen MEA sections were used in Quebec City and 12 in the Vancouver region (out of 29): curb ramps; sidewalk; parking; outdoor signage; doors; accessible routes; walls; obstacles; access ramps; handrails and guardrails; elevators; equipment (automatic teller machine); locker rooms; toilet, changing and shower stalls; and washrooms. Non-compliant items were similar in Quebec City and the Vancouver region. The most frequently encountered ones were similar in both locations. The most problematic MEA sections (with more non-compliant items) were access ramps and washrooms. This study provides a better understanding of the objective characteristics of outdoor and indoor environments impeding access among mobility device users, and consequently, the elements which should be considered for improvement.

Keywords: mobility limitation, environmental barriers, social participation.

Introduction

According to the most recent Canadian Survey on Disability, in 2012, over 7% of Canadians over the age of 15 years (about 1,971,800 individuals) reported having a mobility-related disability (Bizier, Fawcett, & Gilbert.S., 2012). It has been estimated that approximately 1,125,000 community-dwelling individuals who were 15 years of age or older used walking aids, representing 4.1% of the Canadian population (of these individuals, 962,290 used canes/walking sticks/crutches, and 465,340 used a walker) (Charette, Best, Smith, Miller, & Routhier, 2018). One percent of Canadians

(288,800 individuals) use a scooter, a manual or power wheelchair for their daily activities and travels (Smith, Giesbrecht, Mortenson, & Miller, 2016).

Manual and power wheelchairs, as well as scooters, are used to facilitate mobility and improve quality of life (Brandt, Iwarsson, & Stahle, 2004; Fomiatti, Richmond, Moir, & Millsteed, 2013; Salminen, Brandt, Samuelsson, Toytari, & Malmivaara, 2009). How ambulation or mobility assistive technologies (MAT) facilitate mobility and improves the quality of life across several facets of an individual's life is depicted in Jutai, Coulson, and Russell-Minda (2009) conceptual framework linking technology to improvement in the quality of life and well-being. The increase in mobility and quality of life is reflected in outcomes such as increased independence (Brandt et al., 2004; Fomiatti et al., 2013; Lofqvist, Pettersson, Iwarsson, & Brandt, 2012) and social participation (Barker, Reid, & Cott, 2006; Hjelle & Vik, 2011; Lofqvist et al., 2012). Likewise, walkers and canes are provided to facilitate ambulation (Porter, Matsuda, & Benson, 2011) and prevent falls (Bateni & Maki, 2005).

Despite many of the legislative changes that occurred in the past years, individuals using MAT still encounter accessibility problems (outdoors or indoors) (Avis, Card, & Cole, 2005; Fomiatti et al., 2013; Hjelle & Vik, 2011; Hoenig, Landerman, Shipp, & L., 2003; Kaye, Kang, & LaPlante, 2000; King, Dutta, Gorski, Holliday, & Fernie, 2011; McClain, Medrano, Marcum, & Schukar, 2000; Meyers, Anderson, Miller, Shipp, & Hoenig, 2002; Mortenson, Miller, Backman, & Oliffe, 2012). Although these important aspects regarding mobility have been documented, we know little about mobility device users' environments (locations they use) with regards to their ambulation or MAT and mobility in general. Many evaluations can be found in the literature to assess public environments; however, many are only concerned with outdoor (Bennett, Kirby, & Macdonald, 2009; Canadian Heritage Parks Canada, 1994; Don MacDowall of Bass International Consulting for People Outdoors, 2004) or indoor environments (Americans with disabilities act [ADA], 1995, 2001; Stark, Hollingsworth, Morgan, & Gray, 2007). Very few take into consideration both outdoor and indoor environments.

Given the current level of knowledge regarding mobility device users and obstacles encountered in the community presented above, our research team is conducting a larger mixed-methods study to describe the components of mobility for mobility device users' daily activities (Routhier et al., 2019). The project described in this paper aimed to objectively describe environmental obstacles that are encountered by mobility device users in two Canadian urban settings.

Methodology

This study is part of a larger mixed-methods multiphase study regarding mobility and social participation in Quebec City and the Vancouver region of mobility device users. Locations (buildings and exterior spaces) to be audited in each city/region were selected in two ways, based on data collected in a previous phase from this larger study (Routhier et al., 2019). Site identification will be presented in the following section. The evaluation used will then be presented (*Measure of environmental accessibility* (MEA)) as well as the procedure for its use. Finally, the procedure for data analysis will conclude this methodology section. The protocol for this study has been approved by the Research Ethics Boards at the *University of British Columbia* (H15-01340) and the *Institut de réadaptation en déficience physique de Québec* (Approval # 2015-424), as well as the regional health authorities of each site. All study participants provided informed consent.

Site identification

In Quebec City, the locations to be evaluated were selected with study participants of the larger study (Routhier et al., 2019) in which PhotoVoice data were collected and individual interviews and focus groups were conducted. During the focus groups, the participants were asked the following questions:

- What barriers to mobility and social participation do people who use different types of mobility ambulation or wheeled assistive technologies encounter?
- What facilitators to mobility and social participation do people who use different types of mobility ambulation or wheeled assistive technologies encounter?
- What changes would you like to see happen to improve your mobility and social participation?
- How would you like to see these changes facilitated?

From these focus groups, participants identified obstacles of the built environment (barriers) that should be evaluated for future improvements. We did not ask to identify the specifics regarding the problematic dimensions or comparisons with constructions codes. In the following section, the tool used to measure accessibility will be presented (allows respect of construction codes, but goes beyond to ensure access). In Quebec City, 25 participants took part in four focus groups.

In the Vancouver region, the identification of the locations to be evaluated was done during community forums in which preliminary results from the larger mixed-methods multiphase study were shared (Routhier et al., 2019). The attendees were asked about obstacles in the built environment (barriers) that needed to be addressed. The attendees included participants from the larger mixed-methods multiphase study and people from the community (city officials and stakeholders). Three community forums took place (one per Vancouver region city: New West, Vancouver, North Vancouver). A total of 10-15 people were in attendance at each of the three community forums. Locations were decided by consensus at each forum.

Evaluation

The *Measure of environmental accessibility* (MEA) was used to objectively describe obstacles for mobility device users. This measure of the accessibility of public environments for individuals with motor, visual, hearing, cognitive and intellectual disabilities is the updated version of the *Measure of accessibility to urban infrastructures for adults with physical disabilities* (MAUAP) (Gamache et al., 2016), in a Canadian context. The MAUAP was originally developed following a literature review on the accessibility of outdoor and indoor environments for individuals with motor, visual and hearing disabilities as well as the consultation of individuals with disabilities, health clinicians, researchers and municipal representatives.(Gamache et al., 2016) It is not based on compliance standards, therefore not dependant on jurisdiction. It has been evaluated for inter-rater reliability and showed mainly good inter-rater reliability indicators in the province of Quebec's context. The revised version (i.e. the MEA) was updated through a new literature review (addition: inclusion of individuals with cognitive and intellectual disabilities which could likely include more mobility device users given co-morbidity) (Gamache, Morales, Noreau, Dumont, & Leblond, 2018). As stated in the paper presenting the development of the MEA, the *Canadian Standards Association*'s recommendations (CSA Group, 2012) were selected as the principal source of information since they are most representative of the possible progress in accessibility and of Canadian practices which can be applied in Nordic countries. (Gamache et al., 2018) Moreover, ISO recommendations (International Organization for Standardization [ISO], 2011) were also used, because of their influence and the fact that they are produced by an issuer of controlled norms developed by a group of experts from different fields. Even so, all data gathered from other sources were considered in the development of the MEA and were added if relevant. (Gamache et al., 2018) The measure is available here: https://www.ciusss-capitalenationale.gouv.qc.ca/mea-mesure-environnementale-de-laccessibilite. The MEA has good inter-rater reliability indicators [most items (71%, 626/882) had AC1 values ranging from good to excellent] (Gamache et al., 2018). The MEA contains 29 independent sections:

Exterior environment:

1. Curb ramps/Curb cuts

2. Pedestrian crossing
3. Pedestrian signals
4. Sidewalk and pedestrian path
5. Designated parking
6. Parking meter, Ticket machine or Toll station

Interior environment:

1. Signage and outdoor access
2. Doors
3. Security
4. Signage
5. Desks
6. Tables and chairs
7. Accessible routes
8. Walls
9. Obstacles
10. Staircase
11. Access ramp
12. Handrails and guardrails
13. Elevator
14. Platform lift
15. Manoeuvring devices

16. Equipment: drinking fountain, ATM, telephone, Trashcans/bins/ashtrays

17. Locker rooms

18. Toilet, changing and shower stalls

19. Washrooms

20. Room and auditorium

21. Library and resource centre

22. Cafeteria

23. Accessible seats

Each item of each section is evaluated on three scales: 1) the actual measure (actual dimensions of environmental factors), 2) the compliance of the actual measure with the item (whether the dimensions comply with the proposed dimensions in the MEA) as well as 3) observations and the proposed modifications. For example, when evaluating the clear width of an exterior door (section 8, item 7: ≥920mm), the evaluator measures a clear width of 900mm. The evaluator indicates 900mm as the actual measure. Since the proposed criterion is ≥920mm, the actual measure is not compliant with the item. For the observations and the proposed modifications, the evaluator can indicate, according to his or her knowledge, whether an obstacle is reducing the clear width or if 180°-hinges could be installed to provide more clear space.

Procedure

According to the site identification procedures, each section of the MEA (Gamache et al., 2018) necessary to objectively describe the problematic environmental elements proposed by the participants were identified. Here is an example of the process undertaken. Based on information from a participant that an access ramp was hard to use because of limited space, this location would be targeted with the MEA. Sections 17 (access ramp) and 18 (handrails) would be used to objectively describe the problematic access ramp. The other sections were not evaluated. If a building was identified without specific environmental elements being provided by the participants, the main building features allowing access were evaluated: signage, door, access ramp, elevator, and washrooms. Evaluations were performed by research assistants.

Analysis

A descriptive portrait of the obstacles encountered in Quebec City and the Vancouver region was made and were compared by identifying non-compliant MEA' items. The non-compliant MEA' items in both contexts were identified, and the frequency at which they appeared in the locations nominated by the participants was calculated. Only items which have been identified as non-compliant in ≥50% of the locations will be presented. Otherwise, almost all items were non-compliant in at least one in the evaluated sample. By identifying those items that are non-compliant in ≥50% of the evaluations, a trend can be observed regarding the more problematic ones, compared to those that are only evaluated as non-compliant once. For MEA sections that have been used only once, the items identified as non-compliant in ≥50% of the locations will not be provided for the same reason, no trend can be identified with only one evaluation.

Results

A total of 19 locations where environmental obstacles were identified by the participants in Quebec City were evaluated. These locations were: pedestrian zone (n=5), municipal building (n=4), mall (n=3), commercial building (n=2), health institution (n=2), restaurant (n=1), theater (n=1) and tourist attraction (n=1). Other locations (n=8) were identified by the participants in Quebec City; however, they could not be evaluated since they were owned by private companies and permission could not be obtained. A total of 15 MEA sections were used to objectively describe these environmental obstacles.

A total of 20 locations where environmental obstacles have been identified by the participants in the Vancouver region were evaluated. These locations were: pedestrian zone (n=1), municipal building (n=4), business (n=5), commercial building (n=2), health institution (n=2), grocery store (n=1), tourist attraction (n=2), restaurant (n=1), senior center (n=1) and swimming pool (n=1). Other locations (n=5) were nominated by the participants in the Vancouver region; however, they could not be evaluated because permission was not granted for the evaluation to take place. A total of 12 MEA sections were used to objectively describe these environmental obstacles.

The information related to the MEA evaluations is provided in table 1, with the non-compliant items in ≥50% of the evaluations. For example, in the curb ramp section of the MEA, the item *1.7-Running slope (66.7%)* was evaluated as non-compliant 66.7% of the time. The detailed results can be found in extra data, including a complete description of the items (complete labels).

Comparison Quebec City vs Vancouver region

For MEA sections that have been used more than once in each location (Quebec City and the Vancouver region), many of the non-compliant items are the same (see table 1). For **section 5**, regarding designated parking, five non-compliant items (out of 10 in Quebec City and out of nine in the Vancouver region) are the same in both locations (in bold in Table 1). These items are not related to the designated accessible parking space per se but to other elements enhancing its access (parking for vans, the separation between vehicles and pedestrian, call bell or assistance, drop-off area). For **section 8**, regarding doors, five non-compliant items (out of 11 in both locations) are the same in Quebec City and the Vancouver region. These items consider the clear width of the door as well as the glass panel, if present (lower and upper edge, width, contrast). For **section 17**, regarding access ramps, eight non-compliant items (out of eight in Quebec City and out of 13 in the Vancouver region) are the same in both locations. These items consider landings (intermediate landing: location, surface, dimensions, and the dimensions of the top landing), the clear width, the ground surface and the manoeuvring area when the ramp leads to a door. For **section 25**, regarding restrooms, 14 non-compliant items (out of 22 in Quebec City and out of 27 in the Vancouver region) are the same in both locations. These items are related to hooks (location and height), the dimensions of accessible stalls, the location of the toilet, the seat length and colour, toilet paper (height, operability and sanitary bin), the clearance underneath the sink, the size of the sink and the location of the soap dispenser.

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Table 1. MEA sections used to evaluate environmental obstacles

MEA sections	Quebec City		Vancouver region	
	# times the section was used	Most problematic items (not compliant)	# times the section was used	Most problematic items
1-Curb ramps/Curb cuts	9	1.7-Running slope (66.7%) 1.8-Running slope-flared sides (77.8%) 1.12-Edge (lip)-slope (77.8%) 1.13-Edge (lip)-width (55.6%)		
4-Sidewalk and pedestrian	10	4.21-Lighting (50.0%)		
5-Designated parking	9	5.4-Reserved parking sign-clearance (77.8%) 5.7-Drop-off marking (55.6%-absent) 5.8-Walkway to entrance (55.6%-absent) 5.9-Lighting (55.6%) 5.10-Number of reserved spaces (55.6%) ***5.11-Parking for vans (66.7%)*** ***5.14-Separation vehicles vs pedestrians (55.6%)*** ***5.18-Call bell or assistance (66.7%-absent)*** ***5.22+23-Drop-off area (88.9%-absent)***	3	
7-Signage and outdoor access	1		14	7.01- Height (64.3%) 7.03-Colour contrast (50.0%) 7.05-Accessibility sign (78.6%) 7.06-Height of accessibility sign (57.1%)

MEA sections	Quebec City		Vancouver region	
	# times the section was used	Most problematic items (not compliant)	# times the section was used	Most problematic items
8-Doors	8	***8.7-Clear width (62.5%)*** 8.9-Contrast-door and door frame (87.5%) 8.10-Contrast-door frame and wall (50.0%) 8.11-Contrast-door and handle (50.0%) ***8.13+14+15+16-Glass panel-lower edge, upper edge, width and contrast (87.5%, 62.5%, 100% and 62.5%))*** 8.20-Space between door and handle (62.5%) 8.39-Detection device (66.7%)	11	8.6-Protective strip (63.6%) ***8.7-Clear width (63.6%)*** ***8.13 + 14+ 15+ 16-Glass panel-lower edge, upper edge, width and contrast (72.7%, 63.6%, 72.7%, 63.6%)*** 8.36-Lighting (54.5%) 8.38+39-Detection device (54.5%) 8.42+43-Manoeuvring area (63.6%)
13-Accessible routes	4	13.15 to 13.17-Orientation guides (50%-absent) 13.18 to 13.42-Tactile tiles (100%-absent)	1	
14-Walls	4	14.4-Contrast-wall and ceiling (75.0%) 14.6-Contrast-walls and doors (50.0%) 14.8-Colouring (50.0%)	1	
15-Obstacles	4	15.1-Signage (100%) 15.2-Clearance and detectability (75.0%) 15.3-Warning feature (75.0%)	1	

MEA sections	Quebec City		Vancouver region	
	# times the section was used	Most problematic items (not compliant)	# times the section was used	Most problematic items
17-Access ramp	6	***17.5-Location intermediate landing (50.0%-absent)*** ***17.6-Surface intermediate landing (83.3%-absent)*** ***17.7-Dimensions intermediate landing (83.3%-absent)*** ***17.8-Clear width (50.0%)*** ***17.11-Dimensions top landing (66.7%)*** ***17.12+13-Ground surface (100%)*** ***17.16-Manoeuvring area (door) (83.3%)***	9	
18-Handrails and guardrails	5	18.10-Guardrails-height (60.0%) 18.11+12-Guardrails (80.0%)		

MEA sections	Quebec City		Vancouver region	
	# times the section was used	Most problematic items (not compliant)	# times the section was used	Most problematic items
	1		11	19.3-Door width (54.5%) 19.4-Door opening time (81.8%) 19.5-Activation time of the door mechanism (81.8%) 19.7-Cab floor (63.3%) 19.8-Surfaces (81.8%) 19.10+11-Handrails' location and shape (90.9% and 63.6%) 19.13-Space between handrail and panel (63.6%) 19.15-Handrails' texture (63.6%) 19.24-Signage height (63.6%) 19.27-Braille signage (54.5%) 19.30-Height of light indicator (54.5%) 19.36+41-Type of and force required for buttons at landings (54.5% and 72.2%) 19.46+49+52-Signage, light when activated and force required for cab controls (54.5%, 90.9% and 63.6%) 19.56+60-Signage and force required for emergency button (63.6%, 54.5%) 19.62+63-Emergency device bidirectional communication and feedback (54.5% and 72.7%)
22-Equipment (ATM)	1			

MEA sections	Quebec City		Vancouver region	
	# times the section was used	Most problematic items (not compliant)	# times the section was used	Most problematic items
24-Toilet, changing and shower stalls	4	24.11-Exterior handle shape (75.0%) 24.13-Exterior handle centre (75.0%) 24.13+14-Exterior handle operability and contrast (50.0%) 24.17+18+20-Interior handle height, centre, contrast (50.0%) 24.21-Locking mechanism type (50.0%)	1	

Discussion

The aim of this project was to objectively describe environmental obstacles (barriers) that are encountered by mobility device users in two Canadian urban settings. Unsurprisingly, it was found that the evaluation of all of the proposed locations where obstacles have been identified included non-compliant items; therefore, most subjective issues that were identified could be verified through an objective evaluation. MEA sections used more than once in both locations provided similar non-compliant items. This suggests that the most frequently encountered environmental obstacles are similar across locations. Two MEA sections generated a greater number of non-compliant items: access ramps and washrooms.

The non-compliant items identified in this research are also similar to those identified in other research projects, whether outdoor (Clarke, Ailshire, Nieuwenhuijsen, & Vrankrijker, 2011; Giesbrecht, Ripat, Cooper, & Quanbury, 2011; Jenkins, Yuen, & Vogtle, 2015; Kerr & Rosenberg, 2009; Millington et al., 2009; Rosenberg, Huang, Simonovich, & Belza, 2013) or indoor barriers (Dos Santos & de Carvalho, 2012; Hammel et al., 2008; Martins & Gaudiot, 2012; Mcintyre & Hanson, 2014; Thapar et al., 2004). Many other studies regarding environmental obstacles for mobility device users only provide qualitative data (e.g., from interviews) (Giesbrecht et al., 2011; Hanson, 2004; Jones & Catlin, 1978; McClain, Cram, Wood, & Taylor, 1998; McClain et al., 2000; Wennberg, Hyden, & Stahl, 2010), not considering the objective threshold (compliance) allowing access to the built environment. As for the objective evaluations used in other studies, most are highly dependent on the construction norms and codes in place, and therefore very context-specific. What construction codes and norms propose might not always the best accessible solutions. The MEA, however, was based on the recommendations found in the literature which best fit the needs of most users (including individuals with motor, visual, hearing, cognitive and intellectual disabilities) as well as the work initially performed in the development of the previous version (MAUAP) with experts. The use of the MEA goes beyond only considering MAT users and could be beneficial for the evaluation of accessibility for other groups of individuals with disabilities. This evaluation targets a larger population and it allowed the identification of environmental obstacles for the studied population (through the identification of non-compliant items), but also allowed the consideration of other groups of individuals with disabilities (visual, hearing, cognitive and intellectual disabilities) for the identification of the compromise allowing access for most (e.g., curb cut height low enough to favour access with a wheelchair, but high enough to be detectable for individuals with a visual impairment using a white cane).

The obtained results indicating that the most frequently encountered non-compliant MEA' items are similar across locations suggest that construction practices might be similar across Canada and could generate similar accessibility issues. All non-compliant items identified in this research should be reconsidered in construction norms and recommendations for improved access for all, especially for the two above mentioned environmental elements for which more non-compliant items have been identified, access ramps and washrooms. The presence of many non-compliant items could be because some of the evaluated locations' design was based on older building codes that were less demanding when it comes to accessibility. Moreover, the influence of the application of existing norms and craftsmanship could be the cause of the observed environmental obstacles. This could also be explored. However, this aspect has not been studied during this project, the information could not be gathered on the year of design of the evaluated infrastructure, and thus the construction code in place could not be identified, determining if the problem stems from the legislation per se or its application.

Since the MEA goes beyond current building codes in the proposed accessibility criteria, and although some of the evaluated locations were quite recent, the proposed criteria might not be met even if their design was fully compliant with the latest building code. The MEA could, therefore, be used to assess the accessibility of public locations (outdoor or indoor) for individuals with disabilities in general to improve specific environmental elements presented in its items.

Limits of the study

Certain limitations of this study should be noted. The sample size (locations) was limited both in Quebec City (n=25) and in the Vancouver region (n=20). Other environmental obstacles or trends could have been observed if a larger sample of locations would have been assessed. For example, those items that have been identified as non-compliant only once or those sections that have been evaluated only once might represent important and common obstacles, but the samples identified by the participants might not have been large enough to ensure recurrence. Even so, a variety of types of locations were evaluated (vocation, date of construction, locations). To allow for the comparison of sites, it was impossible to attain an equivalent match between the number of MEA evaluations for each section in Quebec City and the Vancouver region (e.g., one elevator evaluation in Quebec City and 11 in the Vancouver region) since the choices made in both contexts were different [might have been influenced by local politics, the weather - timing of the year when the focus groups took place and the preciseness of the choices made by the participants (e.g., a greater number of elevators were assessed in Vancouver since more buildings were identified but in general terms, without targeting specific problematic environmental elements, and elevators was one of the MEA sections that was evaluated when the identification of the building was not specific to an environmental element)]. Therefore, the observed trends between locations are not generalizable. Moreover, many of the MEA sections have not been used, meaning that obstacles related to the elements evaluated in these sections were not identified. The MEA sections used in this study were dependant on the participants' choices to nominate locations and obstacles found within them; therefore, some non-compliant issues may be missed. The geographical sectors in which the evaluations took place were also limited since the study took place in two specific regions/cities (Quebec City and the Vancouver region). Other obstacles might have been more frequently observed in other locations/provinces. In both locations, no evaluations took place when snow or ice was present, which could have changed the findings. Finally, the evaluators in Quebec City and the Vancouver region were not the same, which could have generated difference in the interpretation of the MEA labels.

Future research

This project was focused on the identification of obstacles for MAT users, but other disabilities should be considered. This research could, therefore, be replicated with individuals with other types of disabilities (visual, hearing, cognitive, intellectual). The identification of the compromise that allows access for the greater number of individuals should be studied for different environmental features. Other locations in Canada could also be targeted to explore provincial variation. Further studies could also examine how policies and regulations, as well as their application, influence the presence of obstacles for individuals with disabilities in different contexts. Evaluations should be performed in different weather conditions, since they can greatly impact mobility. Moreover, the entire MEA could be administered in equivalent numbers of locations in different contexts to allow for better quantitative comparisons for its entire content. Measures of accessibility, such as the MEA, should be updated as more accessible practices proposed in the literature are tested with users to provide accurate tools to measure access, for the improvement of the level of accessibility of outdoor and indoor environments based on evidence-based practices. A complementary approach, combining subjective feedback and the objective evaluation of the environment for individuals with disabilities, could be used to identify how modifications to the environment should be prioritized and how construction practices could be improved. Environmental improvements to the encountered obstacles could be identified collaboratively with individuals presenting different types of disabilities, and examples of best practices should be shared. Finally, intervention studies could be performed to look at the impact of changes based on recommendations identified through the use of accessibility evaluations such as the MEA (potential versus costs of those changes and impacts on people with disabilities).

Conclusion

This paper identified environmental barriers hindering mobility and social participation for mobility device users in two Canadian urban settings. The use of the MEA could provide a good basis on which to modify the environment for it to be more accessible. Using it, based on the population's needs, focuses on what is truly important to users. The corresponding objective evaluation allows the formulation of recommendations for adaptations to be made that would best fit most individuals (with different types of disabilities). The complementary approach used, combining subjective feedback from participants and the objective evaluation of the environment for individuals with disabilities, could be an interesting approach to apply in different contexts for the improvement of the built environment and equitable access. This study, therefore, provided highlights the objective characteristics of exterior and interior locations impeding access for individuals with mobility limitations using an MAT (non-compliant items), and consequently, the elements which should be considered for improvement, especially access ramps and washrooms.

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RESEARCH, ANALYSIS, AND EVALUATION OF WEB ACCESSIBILITY FOR A SELECTED GROUP OF PUBLIC WEBSITES IN BULGARIA

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Abstract: This article discusses the accessibility of public information on the Internet by people with disabilities, and in particular people with visual deficits. Web accessibility standards, content and basic principles have been considered. A survey on the accessibility of public websites in the Republic of Bulgaria was conducted. Information on the group that conducted the study is given, the purpose of the study, the methodology of the study is described. The surveys were conducted on 100 public administration sites, which are divided into 5 groups. The results of the study are presented. Conclusions were made for the accessibility of information in the public sphere of the Republic of Bulgaria. In recent months accessibility of these sites has been re-evaluated. The results show that not enough is being done to achieve accessibility while maintaining public administration websites in Bulgaria. Despite the overall increase in web accessibility of the sites being

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tested, there is still much work to be done on this. A statistical analysis of the different groups of public sites was conducted, and the group in which the accessibility was the best was examined.The conclusion is that the accessibility of the websites of the public administration in the Republic of Bulgaria is not at the necessary level of accessibility, which does not allow the users with visual disability to access these sites easily. It is, therefore, necessary for the public administration and web application developers to implement the accessibility guidelines proposed in the standards and improve the accessibility of these websites. This will be a step forward in ensuring the rights of people with disabilities. The paper of this survey is original and not previously published.

Keywords: People with disabilities, accessibility, public information, data analysis, web accessibility standards.

Introduction

The universality of the web implies universal access to the resources and opportunities it offers. It only needs to be connected to the global network and a variety of communication, education, information, commerce, work, and entertainment tools are available (Anctil, 2008; Kane, Shulman, Shockley, Ladner, et al., 2007).

The virtual environment on the Internet must be accessible to all its visitors and not discriminate against some users. Today, the worldwide information network is still not equally accessible to all its users. People with special needs face serious problems, barriers when trying to use the websites on the global network. This practice does not allow these people to read, manage, understand and create content. Typically, this group of users is categorized as "Disabled People (PD)".

The disability is temporarily or permanently difficulty or dysfunction of the body, sensors or cognitive processes. The disabilities are varied and influence to varying degrees in everyday life of the individual in individual cases. Combinations between different types of disability are also possible, which further aggravates the functioning of the individual.

There are several barriers that people with disabilities face in their desire to have a life like other people. According to a report of the World Health Organization and the World Bank since 2011, the total number of people with disabilities is 15 percent (World report on disability). It is not known globally what percentage of their total number are active Internet users, but they certainly experience practical difficulties and even the inability to use part of the web content. The reasons for this can be found in the lack of information about the problem, as well as in the lack of awareness of the web accessibility standards. In any case, the primary reason is how the information is located on public sites. Access to this information should meet the needs and expectations of people with disabilities (Rahmatizadeh & Valizadeh-Haghi, 2018). People with disabilities use the Internet with appropriate access tools (Kurt, 2011).

Public web sites contain interesting information for people, useful data and up-to-date information. Accessibility of people with disabilities to public web sites should be organized so that people with disabilities can easily use it.

Creating friendly set up sites for people with disabilities is a difficult task because people do not have equal experience and the same ability to work with sites (Lee & Koubek, 2010).

Background

Today, there is an increase in the number of people with disabilities who want to actively use information in the World Wide Web (Harrison, Barlow, & Williams, 2007). It is therefore important that the accessibility of public websites is of a sufficiently high level and that persons with disabilities can easily and conveniently access the information in them. When an organization does not take into account the need for people with disabilities to use its services, it does not take them into account as part of its users and does not seek to provide them with access (Wegge & Zimmerman, 2007). Website accessibility research shows no good results for the use of sites by disabled people (Hassouna, Sahari, Ismail, 2017). Therefore, website designers should begin to comply with the accessibility guidelines set out in the relevant standards, not just ensure the quality and information security of the sites (Cocquebert, Trentesaux, & Tahon, 2010).

In their study, Bradbard & Peters (2010) review current author studies on accessibility to the World Wide Web, review tools for creating and evaluating website accessibility, and provide practical tips for making university websites accessible.

Evaluating the accessibility of a website is a difficult task, each website is designed in a specific way, and disabled users may encounter various difficulties (Lee & Koubek, 2010).

Guided by the goal of contributing to improving the accessibility of information on the worldwide network of young people with disabilities who want to get a good education, many studies have evaluated the accessibility of university websites (Solovieva, Bock 2014; Ringlaben, 2014; Maisak, 2015, Nir, 2018; Stitz, & Blundell, 2018).

Kurt (2011) surveyed accessibility levels of Turkish University's home pages, which found that accessibility guidelines were not followed; the author makes recommendations for improving accessibility. In 2015, the survey was repeated and found that overall the accessibility of the pages studied was not improved (Kurt, 2017). The most common omission is to provide equivalent text alternatives for content.

In their research, Thompson, Comden, Ferguson, Burgstahler § Moore (2013) conduct a semi-automated web search for web / IT accessibility policies in higher education universities in the USA. The survey found that accessibility was different across sites, finding an alternative text for the images. 8.4% of universities apply the principles of accessibility. The websites of self-contained institutions provide a higher degree of accessibility. The study found that university websites in the United States were not sufficiently accessible.

Web Accessibility Standards

The type and degree of disability determine the nature of the problems people with disabilities encounter on the Internet. Web Accessibility Standards are aiming to get acquainted all interested in the problems, related to people with disabilities, and addressing the needs of individuals, organizations, and governments on an international scale (Web Content Accessibility Guidelines).

The most widely accepted standard for Web accessibility is the Web Content Accessibility Guidelines (WCAG). The current version at the moment is 2.1. The standard is produced under the leadership and with the active involvement of the World Wide Web Consortium (W3C). Essentially, it is a robust, explanatory technical standard. At the same time, it is technologically independent, i.e. different technologies can be used to implement it.

The WCAG 2.1 standard contains many recommendations for creating more accessible web content. The implementation of these guidelines should make web content more accessible to a wide range of people with disabilities, People with blindness and low vision, deafness and hearing loss, learning difficulties, cognitive limitations, reduced mobility, speech problems, photosensitivity and various combinations of them (Web Content Accessibility Guidelines). The purpose of these recommendations is to make web content more user-friendly.

The WCAG 2.1 standard is a set of recommendations for achieving more accessible web content. Following these guidelines, the content will be more accessible to people with different types of disabilities such as blindness and low vision; deafness and hearing loss; mental disabilities; cognitive limitations; restricted movement; speech impairment; photosensitivity, and others. By following these guidelines, usually, the web content will be more usable for users. From 2012 the current version at that time WCAG 2.0 is an ISO standard (ISO/IEC 40500:2012).

Web Content Accessibility Guidelines 2.1 is the official standard of the 5th of June 2018 (WAC Recommendation, the 05th of June 2018). The version WCAG 2.1 builds up WCAG 2.0. The latest accessibility standard chain created builds on and is compatible with previous versions; it was created to help improve accessibility for disabled users' sites. The 17 new Success Criteria have been added to help mobile users with a disability; individuals with low vision; individuals with cognitive or educational disabilities; Speech-to-Text software users.

Contents of WCAG 2.1 standard

The standard is hierarchically organized. It is subordinate to four principles (P). To every principle, it has one or more of several guidelines (G). Their total number is 12-13 (according to the WCAG 2.1 website). A total of 78 success criteria (SC) are available for each guideline. SCs are the basis of the standard, as with them, the accessibility of the content is tested. Principles and guidelines serve for their logical organization.

The four principles of the standard are the following:

P1. Perceivable – the user interface and the information on the site should be so presented to users so that they can be easily understood. This means that consumers must be capable of perceiving the information provided (it should not be hidden for all their senses);

P2. Operability - It is necessary to achieve easy manageability of the user interface and the provided navigation. Users must be able to use the interface (the interface can not require an interaction in which the user can not participate);

P3. Understandability - The information found on the site and the work of the user interface must be able to be easily understood. Consumers need to be able to understand information and the work of the user interface (content or management should not be beyond their understanding);

P4. Robust- Content must be robust to be reliably interpreted by a wide range of consumer agents and assistive technologies. Users must be able to access the content in sync with advances in technology (with the development of technology and consumer agents, content must remain accessible).

Each success criterion is assigned to any of the three levels - A, AA and AAA. The lowest level is marked with A, and the highest level with AAA. Success criteria of level A typically refer to the widest range of users and more than one disability. The criterion of level A gives the least visual impact on site performance, and its execution would be the least complicated. Criteria of level AA are also of major importance for PD, although sometimes they have a narrower scope and compliance may have an impact on the overall vision of the site. Criteria of level AAA are typically targeted at specific user groups and are more complex and resource-intensive to implement (Bogdanova, Sabev & Tomov, 2014).

The next element of the standard are techniques for implementing the success criterion and sample code. Techniques are updated twice a year and are not necessarily mandatory.▫

There are:

1. enough techniques - a safe way to meet the criteria for success.
2. consultative techniques - recommended ways to improve accessibility. They are not considered as enough techniques.

3. failures - circumstances that place barriers to accessibility.□

We will present below a sample code intended to show only the specific item discussed at the point of purchase. It may not be the best practice for other aspects of accessibility, unrelated to that technique.

Specific example of placement label for MathML. The example shows the MathML function with the role math, appropriate label and MathML presentation:

```
<div role="math" aria-label="6 divided by 4 equals 1.5">

<math xmlns="http://www.w3.org/1998/Math/MathML">

<mfrac>

<mn>6</mn>

<mn>4</mn>

</mfrac>

<mo>=</mo>

<mn>1.5</mn>

</math>

</div>
```

Methodology

Goal and scope of the survey

In many countries a number of studies have been conducted about the accessibility of sites by the public sector. The experience from previous similar studies (Kurt, 2011; Lazar, Allen, Kleinman, & Malarkey, 2007; Mankoff, Fait, & Tran, 2005; Ringlaben, Bray, Packard, 2014; Wentz, Bittle, Hidey & Vickers, 2013) has been studied, adapted and applied to selected sites in the Bulgarian public sector.

The purpose of the study is to examine the accessibility of public administration sites in the Republic of Bulgaria.

Based on the success criterion of Web Content Accessibility Standard in the Republic of Bulgaria, a survey was carried out on 100 websites of public institutions. This is the most comprehensive accessibility study for disabled people conducted on the territory of the country. Its planning and implementation were carried out by the Horizons Foundation, with the participation of the authors of the project "Civil Initiative for Web Accessibility in the Public Sector", financed under the Program for Support of Non-Governmental Organizations in Bulgaria under the Financial Mechanism of the European Economic Area 2009-2014. The study was conducted within 9 months in 2015-2016.

In September and October 2019, the survey was repeated by one of the authors of the paper (with 100% visual impairment), expert, who participated in the first survey, IT specialist The results of the two surveys were compared.

Selecting on sites for testing

The selection of 100 sites to be tested for the purpose of the study was made by the Foundation of the Blind in the Republic of Bulgaria, the selection criteria being the following: to test those public administration sites that are most needed, most useful, most visited by people with visual impairments in the Republic of Bulgaria.

The website's accessibility evaluation can be performed in two ways: manually by experts or by applying automatic tools (Rahmatizadeh, Saeideh Valizadeh-Haghi, 2018). Both methods were applied in the study: the method of direct testing by people with visual impairments and the automatic method. Testing by participants volunteers with severe visual impairments who are not familiar with computing technology can only be manual, so the tests provided give a real idea of the ability of people with visual impairments to use the sites. About 50% of the websites are also tested by visually impaired IT professionals (project experts and Horizons Foundation representatives). A site testing and evaluation method were selected using a questionnaire with a maximum score of 111 points. Experimental testing of 70 public Internet sites was conducted with an online questionnaire of 25 volunteers and five mentors. Key project experts tested the other 30 websites.

Analysis of the information structure of the sites was developed, it was examined whether the sites contain: site map, content map, structural grid; content types, navigation types, general vision of the site and more.▫

Second Testing

The re-evaluate the accessibility of the websites was conducted in September and October 2019. A combination of manual and automated testing was used. Testing was performed using the same questionnaire as the first testing. The new testing takes into account the changes included in the WCAG 2.1 standard. The new evaluation should be based on the WCAG 2.1 standard, which is what is required in the European Union.

For some of the criteria when testing websites, the following two tools are very appropriate and are used in the testing process: Wave (Wave – web accessibility evaluation tool) and aXe (Developer Tools for Web Accessibility Testing).

Purpose of the study

The purpose of the research was to determine the degree of accessibility of public websites in Bulgaria for disabled people and to prove the working hypothesis that public sites in Bulgaria are not sufficiently accessible to people with disabilities. To achieve the stated goal, the tasks of studying the methods and sites, the testing of the selected sites was provided, the analysis of the results and the conclusions of the study were formulated. According to W3C (Website Accessibility Conformance Evaluation Methodology, 2014) in assessing each accessibility site for disabled people, it is recommended to determine the scope of the assessment; researching the targeted website; selecting a representative sample; an audit of the selected sample; findings.

Stages of the study

The study was conducted in several stages:

1. Theoretical - The documentation of Web Content Accessibility Guidelines has been studied, translated in Bulgarian, systematized and optimized. At this stage, the Web Accessibility Handbook (Bogdanova, Sabev, & Tomov, 2016, in Bulgarian) has also been developed. Current methods have been explored for evaluation accessibility of sites for people with disabilities.

2. Preparatory - materials were provided in an optimized volume of testing groups (participants and volunteers). Testing and assessment of web accessibility for people with disabilities were also conducted.

3. Practical - It was created an online questionnaire form from the Guide to be completed by each examiner.

4. Final - At this stage, the results obtained were summarized and analyzed, with the relevant conclusions and recommendations presented at a press conference and at the same time provided to the relevant institutions.

Scope of the study

The conducted research was focused only on sites of public institutions on the territory of the Republic of Bulgaria, grouped in five groups, as follows:

- Group 1: Central State Authorities (President, Council of Ministers, National Assembly, Bulgarian National Television, Bulgarian National Radio, Ombudsman) - 6 web site.
- Group 2: Ministry of the Republic of Bulgaria - 18 web sites;
- Group 3: District administrations in the Republic of Bulgaria - 22 web sites;
- Group 4: Municipalities in the Republic of Bulgaria - 26 websites;
- Group 5: Agencies, committees, and others - 28 websites.

A full description of all sites tested with names of tested public sites and links to them is given in the List URL of the analyzed of 100 public web sites in Bulgaria for Accessibility Testing (List of 100 public sites, 2019).

Accessibility of content - the presentation of information and user interface components - has been studied.

The testers were people with disabilities with varying degrees of impaired vision, which gives a more realistic assessment of the practical accessibility for this group of people. Testing was limited to AA success criterion from Web Content Accessibility standard, as out of the total criterion success, those that do not directly affect the target group of visually impaired people have been excluded.

Model of testing

The study of public web sites in the practical and final stages was organized according to the following model:

- Selection and formulation of research questions (to be linked to the AA criterion success);

- Creating an interactive online question and answer form;
- Survey, scope, and choice of site evaluation system;
- Exploring and conducting of tests for each site (for compatibility with AA level);
- Evaluation of the sample sampling for each site (for compatibility with AA level under standard);
- Generating site survey results in tabular form and graphical appearance (diagrams);
- Analysis of results and conclusions;
- Correction of obtained results, taking into account the human subjective factor.

The developed online questionnaire is a web accessible to disabled people. It contains thirty questions (Table 1) that are directly related to the Web Content Accessibility Guidelines Standard successful criterion. The questions cover the first three principles of the WCAG standard. Each site has been researched and representative samples of test pages have been selected, all pages of the site tested if possible. Major research has been done through the so-called “consumer” testing of sites with visually impaired people (IT specialists and volunteers). Approximately 50% of websites have been tested by visually impaired IT professionals (project experts and representatives of the Horizons Foundation).

Table 1. Questions in the conducted survey and number of response options

Number	Question	Provided for response
1	When you open the page is there automatic loading of a sound with a duration longer than 3 seconds?	2

Number	Question	Provided for response
2	If the duration of the sound that is automatically loaded on the page is more than 3 seconds, can he be easily stopped or his power to decrease without affecting the speech synthesizer volume?	3
3	If the site contains a navigation menu or advertising information, which is located on many rows, is there an opportunity for skipping this section?	3
4	If the site contains multiple rows, were they realized as the headings of the parts as separate titles (headings)?	4
5	If the site contains a hierarchically organized complex system of titles, were they made like titles of different levels?	4
6	Is there a map of the site in an accessible HTML format?	2
7	Do the frames and regions names indicate what is contained in them?	4
8	The elements of which the sites are built, were they structured well? Were they stacked in blocks?	2
9	Is there an explanatory text for graphic images?	4

Number	Question	Provided for response
10	Are active elements used without text information?	3
11	For web forms in which information needs to be filled in - were understandably and cleary titled their fields and elements?	4
12	If verification is provided of the correctness of the data entered in the webform, were the diagnostic messages appear in a place in which will be easily noticed by a screen reader?	4
13	Are there any active elements, the type of which is not reported by systems for speech accompaniment?	3
14	Does the site contain links or buttons whose text does not suggest the action that will be performed upon activation?	3
15	Are there fonts to increase the font size and provide a contrasting view?	3
16	Are the colours mixed together? Is there a good contrast in the colour ratio?	3
17	Is there a possibility to exclude the predicate’s actions? (Word or phrase writing)	3

Number	Question	Provided for response
18	If there is animation or video on the site, are there any text or speech, which explain to them? If the site provides information via speech reproduction (voice recording), has here a text that renders the same information?	4
19	If the site has text depicted as a graphic to confirm that the person who is opening is a human, not a robot, is there alternative access to the text?	2
20	Are the values, rendered as graphics and diagrams, depicted in digital form - text or tables?	4
21	When the mouse pointer crosses a plot with a certain action, is there an alternative activation of said action?	4
22	If provided refresh site content through definitely time, is this leads to difficulty in screen reading reader?	3
23	If the page contains text in different languages, is it used to designate the language of the web page and the individual fragments of her?	4
24	Does the page contain active elements with which the screen reader can not interact?	4
25	Does the page contain active elements with which the screen reader can not interact?	3

Number	Question	Provided for response
26	Can all actions provide on the site be performed using a keyboard?	3
27	If the site sets time limits for certain actions, can these limits be easily extended or discontinued?	3
28	Is it necessary to respond to a specific action at a specific moment?	2
29	Are the documents, downloaded from the site, made in an accessible format for work with a screen reader?	4
30	Specific remarks and recommendations.	

Information about participants - volunteers who have tested web sites

Experimental research and testing on the proposed model of 70 of the surveyed public Internet sites were carried out by 25 volunteers and five mentors. The remaining 30 websites have been tested by key project experts.

Demographic profile of respondents

This section analyses the various demographic characteristics of the respondents (25 volunteers).

Main criteria for selecting volunteer participants:

1. Volunteers must be blind and thus meet the target group of Horizonti Foundation conducting the survey;
2. they must have a good command of computer applications and the Internet;
3. Volunteers should be well acquainted and use a screen reader in their day-to-day work.

Age distribution

The age distribution of the respondents who participated in the study is provided in Table 2. The volunteer participants have a lower age of 22 and the upper 64 at the time of the project tests.

Table 2. Age distribution of the respondents

Age group	The number of people	The percentage represented in the population
21-29	5	20%
30-39	4	16%
40-49	12	48%
50-59	3	12%
60-69	1	4%

Gender composition

The gender composition of the respondents was 19 males and 6 females.

Educational background of respondents

Participants with higher education: 17

Participants with secondary schooling: 8

Among the volunteers, there are participants with higher education and participants with secondary education, which makes it possible to assess the web accessibility of the sites by participants with different degrees of education. At the same time, the different education factor is not considered as determining for the study.

Employment

At the time of the project tests in the group, there are six unemployed (for three of the participants missing information).

Degree of visual impairment

1. Six people with low vision;
2. Eighteen fully blind;
3. One colourblind.

The volunteer participants are from different localities of the Republic of Bulgaria: Varna, Dobrich, Burgas, Silistra, Gabrovo, Plovdiv, Perushtitsa and Sofia. This selection of visually impaired volunteer participants gives an idea of how participants from different territorial areas can handle the challenges of the global network.

Results

Results of research and testing on public sites

The majority of the test participants (96 .5%) used a screen reader with a speech synthesizer in the test process; while 3.5% of the participants - a software screen magnifier. The two most popular screen readers used in Bulgaria - NVDA (the current version in the moment of the test) and JAWS (versions 14 to 17) and, to a lesser extent, screen magnifiers were used in the tests. The browsers used in testing are also varied - Internet Explorer is represented by two versions - 11.10, Mozilla Firefox (versions 44, 43, 33) and Google chrome by not specifying the versions used. The different types and versions of operating systems, browsers and screen readers, with which the test is performed, influence the results and contribute to their more difficult comparability. Based on the developed assessment methodology, the evaluation score obtained ranks the sites in groups according to their degree of accessibility, and for each group, the following points are specified:

- Inaccessible site - under 30 points;
- Low accessible website - from 30 points to 50 points;
- Partially accessible site - from 50 points to 80 points;
- Affordable site (to a large extent) - with over 80 points.

It is important to emphasize that such accessibility assessment for Web Content Accessibility Guidelines not defined. A site is classified as either accessible or inaccessible. This grouping by category was chosen by the authors to provide a more comprehensible presentation of the results to a broader audience.

Necessity from the applied model correction

When conducting user testing by volunteer participants, there is a possibility that some of the results obtained, which take into account the accessibility of information on public sites, may prove to be inadequate due to the influence of the subjective human factor. This subjective factor always has its influence because human beings are not unified units. The reason for the influence of the subjective factor may be, for example, the different levels of knowledge of accessibility technologies used, different computer literacy and lack of experience in using technology. A significant drawback of such testing methods is the application of the principle of testing one site by one person only. If the user who performs the test is not very experienced, he will not be able to cope optimally with the specific situation, and this will influence the final evaluation. It is a good idea to reduce the weight of the assessment when conducting testing by volunteer participants with insufficient computer skills and knowledge, as these assessments are either not taken into account or rechecked. Another obvious disadvantage of the assessment methodology is the weight greater than a unit of some of the questions. This approach may also lead to distortion of the results. In the binary evaluation with “yes” and “no” (0 and 1), this subjectivity can be avoided. From this point of view, the proposed and experimental testing methodology needs improvement.

The point at which some of the questions are inapplicable to a site should also be refined. An example of such a question is the availability of available video content in the research site. In the present study, the lack of video content is considered as a positive fact and increases accessibility assessment for that site. When this is combined with the added weight of the issue, there is a possibility that the distortion of the results will increase. The reason is that, in the absence of some inaccessible elements, points are given which, in certain cases, attach more weight to their lack than to the availability of accessible ones. This makes it possible for the phenomenon of inaccessible or more difficult to use websites in overall results to be equally accessible or more accessible than sites with a higher level of accessibility.

The participants - experts conducting and evaluating the survey - performed an initial review and analysis of the results of the given questions. To make the results more accurate, additional testing and corrections were required. For example, one of the sites tested, which was known to past visit experts as practically inaccessible, in the test proved to be relatively affordable. New tests and fixes for the site’s results were made. New tests were also made for other inconsistencies noted.

The drawback of the deficiencies so identified is that the proposed testing methodology can continue to be developed and that new improvements and corrections are introduced to counteract the negative effects on the outcome of the tests.

Conclusions and findings

Following the corrections and control iterations of some of the tests, the conclusion and analysis of the results resulted in the following conclusions:

1. In Access Category 4 (a widely accessible site) 50% of sites are included.
2. Access to the remaining 50% of the sites tested is problematic.

The conclusions concluded confirm the initial working hypothesis that a large part of the researched sites in the public sector in the Republic of Bulgaria is inaccessible for people with disabilities (for level AA).

A particularly striking example of inaccessibility under the Success Criterion 1.1.1 is the so-called CAPTCHA - Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA: Telling Humans and Computers Apart Automatically). Based on the survey results, 60% of sites use CAPTCHA (Question 19, Success Criterion1.1.1). This has led to the visually impaired visitor being prevented from entering the web site, as for most people with visual impairment, a suitable alternative is not provided. 10% of these sites provide an affordable alternative, and 20% of sites do not exist. In most cases, the difficulty extends beyond eliminating whether a visitor is a robot or a person. So the web developer manages to eliminate access for well-meaning internet users as well.

Below is a list of some of the other findings made about the accessibility of public sites:

1. Missing or incorrect use of HTML headings (titles);
2. Absence of meaningful alternative text to the images;

3. No links to skip to the main content;

4. Insufficient colour contrast, among others.

From the results and the findings that only half of the sites surveyed can be identified as being relatively accessible to disabled people, the main conclusion is that public sector sites in Bulgaria have not yet gone their way to the global and European requirements - AA level.

Summary of test results

Accessibility category 4 (a widely accessible web site) accounts for 50% of the web sites. Access to the remaining 50% of the web sites tested is problematic.

The results prove that the underlying hypothesis corresponds to reality because 50% of the sites surveyed proved to be difficult to reach for blind users.

Some examples:

1. Slightly accessible

   In this category are the websites of Commission for Protection of Competition, Bulgarian National Television, Ministry of Labor and Social Policy, Ministry of Agriculture and Food, Patent Office, Agency for People with Disabilities; the websites of municipalities Sliven, Rousse, Vidin; web sites of regional administrations Vratsa, Varna, Bourgas and others.

2. Highly accessible

   This category includes the websites of Commission for Protection against Discrimination, Agency for Social Assistance, Ministry of Internal Affairs, National Statistical Institute, Bulgarian Posts, the sites of regional administrations of Blagoevgrad, Dobrich, Razgrad, Sliven, municipalities Samokov, Varna, Razgrad. Velingrad, Koprivshtitsa, and others.

Using the results obtained from the research in the future work of the authors

Good solid experience has been gained in the study of the accessibility of public websites in the Republic of Bulgaria, a successful methodology for testing web accessibility has been created and improved, experience has been gained in working with people with special needs. The results obtained regarding the accessibility of the public websites in the Republic of Bulgaria and the main problems encountered by people with disabilities (and, more specifically, people with visual deficits) will be used in the future work of the authors' team on accessibility issues. An information website is to be developed by the members of the team, which aims to inform the public about the work and the results of the project team in the field of research of mathematical technologies for processing and analysis of physiological data. The made conclusions and findings from the study described in this paper will be applied to improve the accessibility of people with visual deficits to digitized databases, information websites and software systems for the analysis of physiological data.¤

Comparison of the two studies

The comparison shows that overall website accessibility has improved (by an average of 17.2%). 6 of the websites surveyed showed a decrease in accessibility. For a large number of sites, there is no change in the results obtained from the new testing performed (compared to the results of the first study). There is a positive change towards increasing the accessibility of websites, but it is small and has not happened in all the websites studied.

Improvements in accessibility were seen on websites that had very little accessibility (less than 32%) when they first tested.

Legal provisions on web accessibility in Bulgaria

The European Parliament and the European Council adopted Directive (EU) 2016/2102 on the accessibility of the websites and mobile applications of Member States' public sector organizations. This document is gaining popularity as the "Web Accessibility Directive". At its core, the Directive seeks to serve both EU citizens and web service providers by facilitating the completion of an internal market for website accessibility, by approximating the laws, regulations and administrative provisions of the Member States on the accessibility of websites.

Accessibility is an integral part of the principle of equal rights for citizens. Article 41, paragraphs 1 and 2 of the Constitution of the Republic of Bulgaria establishes the right of access to information and freedom of expression and opinion as a fundamental principle. Everyone's right to "seek, receive and impart information" is guaranteed as well, and all citizens have the right "to receive information from a public authority or agency on matters of legitimate interest to them if the information is not state or other secretly protected by law, or does not affect someone else's rights" (Constitution of the Republic of Bulgaria,2015).

New disability law (in force since 01/01/2019) repealed the old disability integration law (Law on people with disabilities, 2018), it essentially regulating public relations in the exercise of the rights of citizens belonging to this social group. The purpose of the law is to create conditions and guarantees for equality, social integration and support for people with disabilities. Article 5 (paragraph 2, point 7) defines accessible information as one of the means of social inclusion of people with disabilities. The directive was supposed to be transposed into domestic law by 23/09/2018, but as this is not yet a fact, this has many negative consequences for Bulgaria. The old provisions of the Law on Electronic Governance and the Ordinance on Electronic Administrative Services apply.

At the moment (October 2019), a law has not yet been adopted in Bulgaria to ensure compliance with the Accessibility Directive of the European Union. Improving accessibility for public administration sites in Bulgaria is currently a matter of voluntary action. The authors of the paper hope this study will help to discuss the problem of accessibility of websites in the Republic of Bulgaria and to solve it soon.

Statistical analysis

To examine the differences in accessibility issues rate among five groups of websites, ANOVA test on the *f*-ratio value and *p*-value was performed. The results were considered significant at $p < 0.05$. Statistical analysis carried out using the IBM SPSS Statistics software, Version 23 (IBM Corp., USA).

The obtained results for the accessibility of the individual site groups in the second survey are shown in table 3.

Table 3. Exploring accessibility in different site groups

	Group 1	Group 2	Group 3	Group 4	Group 5
Accessibility assessment [%]	78±15.21	93.00 ±7.43	80.5±16.75	82.88±15.24	84.86±13.84
p-value	p-value (1,2 group) 0.003088	-	p-value (3,2 group) 0.00565	p-value (4,2 group) 0.012719	p-value (5,2 group) 0.027015

	Group 1	Group 2	Group 3	Group 4	Group 5
f-ratio value	f(1,2 group) 11.04287	-	f(3,2 group) 8.60696	f(4,2 group) 6.77515	f(5,2 group) 5.23384

Statistically significant differences were found when comparing the second group (with the best accessibility scores) with each of the other groups. Statistically significant difference among the 1 and 2 groups is $p<0.001$. Statistically significant differences were also found between all groups (f-ratio value is 2.47607. The p-value is 0.049356).

Conclusion

The article presents the results of two surveys conducted on the web accessibility of public sites in Bulgaria by people with disabilities (in particular people with visual deficits). The article describes the web accessibility standards on which the study is based, the survey participants, the methodology and the way the survey is conducted, and the online questionnaire created for the survey. Questions cover opportunities, ways of coping, and the time required to access web resources. The results obtained are based on the responses of people with disabilities - experts and volunteer participants.

The second survey shows an increase in the accessibility of some of the surveyed public websites in Bulgaria. However, this increase is small and not sufficient to achieve adequate accessibility for the convenient use of the sites by people with visual impairments. The conducted statistical analysis shows that the availability of the websites of the ministries in the Republic of Bulgaria is the best, which indicates the willingness of the maintainers of these sites to provide accessibility for disabled people.

The main conclusion is that a small part of the surveyed public sites in Bulgaria is accessible to people with disabilities. Much of the sites make it difficult for people with disabilities, and only a small part of the sites are fully accessible. It is concluded that web developers in the Republic of Bulgaria should aim to improve the web accessibility of information on public sites for people with disabilities. The conclusions will be used in the future work of the authors of the article - creating a web site for the current project of the team and a software system for analysis of physiological information. The aim is to achieve a successful inclusion in the research work on the processing and analysis of physiological data by a member of an authoring team having this problem. For the results achieved in this direction, the authors will report in their next publications.

The conclusions made of this study and the experience gained will be used by the team in their current work on a research project in the field of the research of mathematical technologies for the analysis of physiological data and the inclusion in this activity of people with visual deficits.

Acknowledgments

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Appendix

List of 100 public sites for Accessibility Testing

1 Council of Ministers of the Republic of Bulgaria, http://www.government.bg

2 Ministry of Economy of the Republic of Bulgaria, http://www.mi.government.bg

3 Ministry of Foreign Affairs, https://www.mfa.bg/

4 Ministry of Interior, https:// www.mvr.bg

5 Ministry of Health, https://www.mh.government.bg

6 Sofia Municipality, https://www.sofia.bg

7 Commission on Protection against Discrimination, http://www.kzd-nondiscrimination.com/layout/

8 Employment Agency, http://www.az.government.bg

9 Municipality of Koprivshtitsa, http://koprivshtitsa-bg.com

10 Municipality of Samokov, http://samokov.bg

11 Ministry of Agriculture, Food and Forestry, https://www.mzh.government.bg/en/ministry/

12 Municipality of Rousse, http://ruse-bg.eu

13 Character Agency, http://ahu.mlsp.government.bg

14 Communication of culture, http:// www.mc.government.bg

15 Ministry of Education and Science, http:// www.minedu.government.bg

16 Ministry of Environment and Water, http://www.moew.government.bg

17 Municipality of Kardjali, http://www.kardjali.bg/

18 Municipality of Razgrad, http://www.razgrad.bg/

19 Kardzhali Regional Administration,

http://www.kj.government.bg/index.php?lang=bg

20 Blagoevgrad District Administration, http://www.bl.government.bg/

21 Ministry of Energy, https://www.me.government.bg/bg

22 Ministry of Defense, http://www.md.government.bg

23 Silistra municipality, http://www.silistra.bg

24 Consumer Commission (CPC), https://kzp.bg/

25 Bulgarian National Television, http://www.bnt.bg

26 Burgas municipality, http://www.burgas.bg/

27 Bulgarian National Bank, http://www.bnb.bg/

28 Pazardzhik Municipality, http://www.pazardjik.bg

29 Veliko Turnovo District Administration, https://vt.government.bg/

30 State Agency for Bulldozers Abroad, https://www.aba.government.bg/

31 Bulgarian Post, http://www.bgpost.bg/

32 Municipality of Kyustendil, http://www.kustendil.bg/

33 National Accreditation Assessment Agency, http://www.neaa.government.bg/

34 People's meeting, http://www.parliament.bg/

35 Operational Program "Competitiveness", http://www.opcompetitiveness.bg/

36 Ministry of Tourism, http://www.tourism.government.bg

37 Public Procurement Agency, http://www.aop.bg

38 Municipality of Vratsa, http://www.vratza.bg/

39 State Gambling Commission, http://www.dkh.minfin.bg/

40 Customs Agency, https://customs.bg/

41 District administration of Lovech, http://oblastlovech.org

42 State Commission on Information Reliability, http://www.dksi.bg/

43 National Legal Aid Bureau, http://www.nbpp.government.bg/

44 Municipality of Varna, http://www.varna.bg

45 Municipality of Vidin, http://vidin.bg/

46 Ombudsman of the Republic of Bulgaria, http://www.ombudsman.bg/

47 Municipality of Lovech, http://www.lovech.bg

48 Ministry of Justice, http://www.justice.government.bg/

49 Municipality of Smolyan, http://www.smolyan.bg/bg/home

50 Vratsa Regional Administration, http://vratsa.bg

51 National Insurance Institute, http://www.noi.bg/

52 National Library "St. St. Cyril and Methodius", http://www.nationallibrary.bg/

53 Bulgarian national radio, http://bnr.bg/

54 District administration Razgrad, http://www.rz.government.bg/bg

55 State Agency for Metrological and Technical Supervision, http://www.damtn.government.bg/

56 District administration of Sliven, http://www.sliven.government.bg/

57 Ruse Regional Administration, http://ruse.bg/

58 Regional administration of Smolyan, http://region-smolyan.org/

59 Municipality of Slivenhttp, http://www.sliven.bg/

60 Silistra District Administration, http://www.ss.government.bg/

61 Commission for Protection of Competition, http://www.cpc.bg

62 Municipality of Velingrad, http://www.m.velingrad.bg/

63 Gabrovo Municipality, https://gabrovo.bg/bg

64 District Administration Plovdiv, http://www.pd.government.bg/

65 Executive agency electronic connection to networks and information systems, https://www.esmis.government.bg/

66 Municipality of Razgrad, http://www.razgrad.bg/

67 Municipality of Pomorie, http://pomorie.bg/

68 Patent Office, http://www.bpo.bg/

69 Pazardzhik Regional Administration, http://www.pz.government.bg/news.php

70 Kyustendil Regional Administration, http://www.kn.government.bg/

71 National Agency for Vocational Education and Training, http://www.navet.government.bg/

72 Plovdiv Municipality, http://www.plovdiv.bg/

73 District administration of Pleven, http://www.pleven-oblast.bg/

74 Municipality of Pleven, http://www.pleven-oblast.bg/

75 Website of the Central Election Commission, https://www.cik.bg/

76 District Administration Sofia, http://sofoblast.bg/

77 President of the Republic of Bulgaria, http://www.president.bg

78 District administration of Pernik, http://www.pernik.e-gov.bg/Harta.htm

79 Gorna Oryahovitsa Municipality, http://www.g-oryahovica.org

80 Operational Program "Human Resources Development", http://ophrd.government.bg/

81 District administration of Gabrovo, http://www.gb.government.bg/

82 Montana County Administration, http://oblastmontana.org/

83 The municipality of Montana, http://www.montana.bg/

84 Pernik Municipality, http://pernik.bg/

85 State Agency for Child Closure, http://sacp.government.bg/bg/

86 Ministry of Regional Development and Public Works, http://www.mrrb.government.bg/

87 Transport, Information Technology and Communication Communication in the Republic of Bulgaria MTITC, https://www.mtitc.government.bg/

88 Ministry of Labor and Social Policy of the Republic of Bulgaria, http://www.mlsp.government.bg

89 Ministry of Finance, http://www.minfin.bg/

90 District administration of Dobrich, http://www.dobrich.government.bg

91 Court of Auditors, https://www.bulnao.government.bg/

92 Youth and Sports Communication, http://mpes.government.bg/

93 Social Assistance Agency SAA, http://asp.government.bg

94 National Statistical Institute NSI, http://www.nsi.bg

95 Registry Agency, http://www.registryagency.bg/

96 Commercial register, http://www.brra.bg

97 National Revenue Agency NRA, http://www.nra.bg

98 Regional administration of Burgas, http://www.bsregion.org/

99 Blagoevgrad Municipality, http://www.blgmun.com/

100 Varna Regional Administration, http://www.vn.government.bg/

DAILY LIFE, ANTHROPOMETRY AND BEDROOM DESIGN OF INDONESIAN ELDERLY

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***Abstract*:** Indonesia elders have a choice to stay in residential or live in a nursing home. Effort should be invested to maintain the elderly well-being despite their lives choice. The purpose of this study is to observe Indonesian elderly who live in residential (either lives independently or with families) and nursing home. In addition, this study also describes the anthropometry of Indonesian elderly, in particular in relation to bedroom design for elderly. One hundred and three Indonesian elderly were involved in this study (mean age = 74.4 years, SD= 8.98 year, 82 female). A total of 15 anthropometry body dimensions are measured based on their relevance to the elder's bedroom design. Results show different activities among Indonesian elders based on their dependencies. The bedroom design for Indonesian elderly is proposed.

Keywords: anthropometry, bedroom design, daily life, elderly.

Introduction

Recently, the number of life expectancy in the world is increasing due to the improvement in nutrition, medical technologies, and economic well-being. By 2050, the number of elderly is expected to be reached 2.1 billion worldwide (United Nations, 2017). Therefore, in some countries, the care of older people is now a national priority. Problems arise with the increased number of elderly. Change in socio-economic status and various health problems affect an individual's way of life during old age. Ageing also influences the economic status due to a change from salary to pension or unemployment leading to economic dependency on children or relatives (Lena et al., 2009).

Concerning one aspect of the socio–economic status, that is the choice of way of living, research has been shown various results. In most countries, the increasing mobility of productive age workers causing elderly care in families to be more difficult (Arifin & Ananta, 2009). Also, the number of elderly patients living in a nursing home rose substantially in the late 1980s and the 1990s (Fahey et al., 2003). However, there is a trend that recently most elderly want to live independently in residential because they do not want any support from their children such as the elderly in Korea (Seo-Ryeung & You-Jin, 2004). Although, it should be noted that elderly lives in residential sometimes having economic, social or physical barriers that affect their overall independence, well-being, and quality of life (Berke, 2014). Some researchers are, therefore, focus on various aspects of elderly living in both residential and nursing home (e.g., Fahey et al., 2003).

In particular, for elderly living in residential, they also have more problems getting about in their own homes in many aspects (Chen, 2009). The problems can be seen, for example, from the pictures of home accidents among the elderly. For that reasons, several studies have highlighted human factor design to support elderly live independently such as house designs in South Korea (Seo-Ryeung & You-Jin, 2004) and Malaysia (Md. Dawal et al., 2015), and bathroom and kitchen design in Brazil (Camara et al., 2010). Thus, the design of the house for the elderly is crucial.

In Indonesia, the percentage of the elderly reaches 9.60 percent or around 25.64 million people in 2019, and 9.38 percent of them live independently (Statistics Indonesia [BPS], 2019). One of the reasons Indonesian elderly are more likely to live independently because they do not always have others to help them (Octavia & Widjaja, 2013). However, many older people choose to stay in the nursing home because there are more facilities and support, such as health facilities and nutrition. In Indonesia, the nursing home operated by the government has the duty to provide guidance and service for neglected elderly in order to live well in the life of self, family, and community. The number of the nursing home, both owned by the government or non-government in Indonesia, is increasing in a significant way as well (Ministry of Social of Indonesia, 2010).

The high number of Indonesian elderly living in resident shows the need of housing facilities that should be designed in accordance with the needs of the elderly to improve their well-being. One of the things that are easily attributed to the design of supportive facilities is anthropometry. Studies of elderly anthropometry have been gaining attention and have been conducted in many countries, both for developed countries (e.g., The US (Pennathur & Dowling (2003), Australia (Kothiyal & Tettey (2000), and Italy (Perissinotto et al. (2002)) and developing countries (e.g., Malaysia (Md. Dawal et al., 2015), India (Reddy et al., 2004), and China (Hu et al., 2007)). However, in author knowledge, no study has been conducted in collecting Indonesian elderly anthropometric data for design purpose, as well as the design for the house of Indonesian elderly. An exception is a study conducted by Setiati et al. (2010) which observed limited anthropometry data of Indonesian elderly in relation to medicine and nutrition; and Hartono (2018) which examined different anthropometry for special population.

This study aimed to observe elderly living in communities and a nursing home in Indonesia as well as the pros and cons of each. The second aim of the present study is to provide anthropometric data of the elderly based on a sample drawn from the Bandung area. The third aim is to propose bedroom design based on anthropometric consideration for Indonesian elderly.

Methodology

Participants

One hundred and three Indonesian elderly are involved in this study (mean age = 74.4 years, SD= 8.98 years, 82 female). They are between 50 to 94 years of age. Data are collected from 5 nursing homes in Bandung. Participants are chosen by convenience sampling method.

Daily Life observation

An interview is conducted to find out the differences in daily life between elderly live-in resident with elderly living in the nursing home. A total of 103 elderly live in the nursing home, and 41 elders live in their own houses are interviewed about their daily activity and living arrangements. The interviews are divided into two parts that are interview to find out the reasons about the elderly living status (i.e., live independently, live with family and live in the nursing home) and interview to find out the differences in the daily life of elderly live independently, live with family and live in the nursing home.

Anthropometric Measures

Anthropometry data are collected using manual anthropometer, which is calibrated before the measurement. These manual measurements are chosen, instead of the sophisticated one, due to practical reasons. A total of 15 anthropometry body dimensions are selected based on their relevance to the elderly' bedroom design. This dimension is selected based on the previous study done to design the bedroom of the elderly (Rahmawati and

Jiang, 2019), which are crucial in the design of an elderly bedroom. The dimensions are stature, standing eye height, standing shoulder height, standing elbow height, standing vertical grip reach, shoulder-grip length, sitting vertical grip reach, sitting eye height, sitting shoulder height, sitting elbow height, shoulder breadth, elbow span, sitting popliteal height, buttock-popliteal length, and hip breadth.

The anthropometry measurements are conducted by a team from Institute Technology Bandung involving senior researchers and 5 research assistants aged 20-22 years. A training session is conducted as a refresher to the assistants in relation to skill in anthropometry measurement, in addition to their several years of experience in our laboratory. The training session is also intended to minimize inter-observer error (Widyanti et al., 2017). The whole survey is completed in three months.

Bedroom Guidelines Design

The guidelines of the elderly' bedroom are developed from literature study, to support the elderly to live comfortably and safely (the process of development of bedroom guidelines for elderly can be seen in Rahmawati and Jiang, 2019). In short, the bedroom guidelines is proposed based on a rigorous and systematic literature study; such synchronization is conducted based on available international standards as well as on the related empirical studies in developing countries (e.g. Rashid, Hussain & Yusuf, 2008; Dvouletá & Káňová, 2014; Md. Dawal et al., 2015). While the results of anthropometric measurements were applied as a guideline to the bedroom design to adjust to the body dimensions of the Indonesian elderly.

Results

Daily Life of Indonesian elderly

Reason of daily lives choice, whether live in residential or nursing home among a sample of Indonesian elderly can be seen in Table 1. The main reason of Indonesian elderly for staying in the nursing home is no support from the family. In Indonesia, elderly who live at home either live alone/independently or with families tend to do more in light housekeeping activities and less in exercise activity. In contrast, Indonesian elderly who live in nursing homes tend to do more in exercise activities (because they have a fixed schedule to do the exercises every morning with a coach or nurse) and less in social engagement such as social networks or social activities.

A study by Wreksoatmodjo (2013) among Indonesian elderly' activities is in line with this result. The similar fact also described by Tahrekhani et al., (2015) who reviewed that the most activities performed by older women in Iran were housekeeping, whereas the most activities performed by older men in Iran was in relation to gadget.

Table 1. Reasons of elderly' living status

	Independently	With Family	Nursing Home
Number or respondents	12	31	103
Age (mean, SD)	67.75 (7.91)	70.77 (8.66)	74.44 (8.98)
Reasons of Living Status (%)			
Do not want any support from family	33	-	27
Family live far apart	58	-	55
No family	8	-	18
Stay with family support	-	87	-
Stay with grandchildren who take care of them	-	13	-

However, another study conducted by Koolhaas et al. (2017) shows that the Netherlands elderly, both men and women spend their most time in sedentary behaviour such as TV viewing, driving automobiles, and reading. It seems that the way the elderly spends their daily times have been influenced by local habit and culture. Knowing the habit and daily activities of the elderly is important because such effort and intervention to reduce elderly' problems are mainly based on the elderly' activities (e.g., Wang et al. 2009). Such problems that are reported by elderly is for example described in the studies by Karakaya et al. (2009) and Scocco et al. (2009) who stated that elderly living in residential shows problems of low mobility, whereas elderly living in nursing home reveals stress and depressive symptoms due to low social engagement. The differences in the daily life of elderly live independently, live with family and live in a nursing home can be seen in Table 2.

Table 2. Differences of elderly' daily life

Activity	Independently (%)	With Family (%)	Nursing home (%)
Morning			
Excercise	8.3	3.2	65.0
Housekeeping	41.7	41.9	15.5
Shopping	16.7	16.1	-
Others	33.3	38.7	19.4
Afternoon			
Do activities of art or hobbies	8.3	12.9	47.6
Farming or gardening	41.7	38.7	36.9
Take a rest	25.0	38.7	-

Activity	Independently (%)	With Family (%)	Nursing home (%)
Others	25.0	9.7	15.5
Evening			
Do religion activities	25.0	25.8	35.0
Take a rest	75.0	74.2	65.0

Anthropometry of Indonesian elderly

Each individual anthropometry data is recapitulated in a piece of prepared paper. Summary of anthropometric data and descriptive statistic (mean and SD) based on gender are presented in Table 3. Rigorous literature study about anthropometry data of elderly in different countries and comparison with Indonesian elderly anthropometry data for the very basic anthropometry data that available in most literature (i.e. stature), can be seen in Table 4. The table shows the importance of anthropometry study of the elderly in many countries with different dimensions and different purposes.

Table 3. Anthropometry data of Indonesian elderly

Dimensions	Male (N = 21)				Female (N = 82)			
	Mean	SD	5th	95th	Mean	SD	5th	95th
1. Stature	156.08	7.30	144.07	168.08	144.87	8.36	131.11	158.62
2. Standing eye height	143.31	7.02	131.77	154.85	132.26	7.43	120.04	144.49
3. Standing shoulder height	129.38	4.84	121.42	137.35	119.25	7.00	107.74	130.76
4. Standing elbow height	98.46	4.65	90.82	106.11	90.38	7.54	77.98	102.77

Dimensions	Male (N = 21)				Female (N = 82)			
	Mean	SD	5th	95th	Mean	SD	5th	95th
5. Standing vertical grip reach	174.00	37.37	112.52	235.48	171.55	14.00	148.52	194.58
6. Shoulder-grip length	76.22	24.45	36.01	116.44	64.42	6.13	54.33	74.51
7. Sitting vertical grip reach	145.93	14.95	121.33	170.53	138.73	22.88	101.09	176.37
8. Sitting eye height	107.52	8.11	94.18	120.86	101.91	13.59	79.56	124.27
9. Sitting shoulder height	94.29	7.66	81.69	106.88	87.46	7.60	74.96	99.96
10. Sitting elbow height	65.76	8.07	52.48	79.04	61.74	6.20	51.55	71.94
11. Shoulder breadth	39.43	2.42	35.45	43.41	37.72	3.77	31.52	43.92
12. Elbow span	81.36	8.58	67.25	95.48	70.84	8.33	57.13	84.54
13. Sitting popliteal height	42.90	3.08	37.84	47.97	40.52	2.51	36.39	44.65
14. Buttock-popliteal length	42.33	4.73	34.56	50.11	40.10	3.50	34.34	45.86
15. Hip breadth	34.71	3.61	28.78	40.65	33.90	3.26	28.54	39.26

As expected, similar facts about significant differences in anthropometry data of different race or countries for children and adult (in which anthropometry data of Caucasian is bigger and taller than Asian in general), is also found in elderly anthropometry data. In general, Caucasian lived in developed countries have a high level of income per capita (International Monetary Fund, 2017). Higher income is associated with better nutrition and better medical and social service that leads to an increase in overall stature (Iseri & Arslan, 2009; Widyanti et al., 2017). However, it should be underlined that the anthropometry data from the different countries presented above are measured and published in the different decade. Since there is a possibility that anthropometry data from one country/area might differ due to the different time of measurement, such comparison is worth to conduct (Hughes et al., 2004).

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Table 4. Comparison of elderly' anthropometry among different studies and different countries

Author (s)	Nation	Number of subjects		Age range of subjects		No. of anthropometry dimensions measured	Mean stature	
							Male	Female
Pennathur and Dowling (2003)	US	Male Female	40 106	All	60 - 85	15	1664	1526
Kothiyal and Tettey (2000)	Australia	Male Female	33 138	Male Female	65 – 92 65 - 92	22	1658	1521
Perissinotto et al. (2002)	Italy	All	5462	All	65 - 84	4	1717	1522
Santos et al. (2004)	Chile	Male Female	411 819	All	60 - 99	4	1646	1498
Coqueiro et al. (2009)	Cuba	Male Female	1197 708	All	60 +	7	1660	1528
Reddy et al. (2004)	India	Male Female	82 65	All	60 +	4	1657	1550
Hu et al. (2007)	China	Male Female	53 60	Male Female	65 – 85 65 - 80	47	1655	1525
Shahida et al. (2015)	Malaysia	Male Female	56 56	All	60 +	38	1611	1499
This paper	Indonesia	Male Female	21 82	All	50 – 94	15	1561	1449

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Bedroom guidelines design

In relation to the proposed bedroom design guidelines for Indonesian elderly based on anthropometry approach, a small pilot study to observe ten existing condition of bedroom design in Indonesia has been conducted. Most of the composition of bedrooms in Indonesia has 6 unit areas such as entrance, bed area, storage units, work area, window area, and control units. Indeed, most of the bedroom specifications are not in accordance with Indonesian anthropometry as can be seen in Table 3. The final result of this study is the design of the guidelines for elderly Indonesian bedrooms which are presented in Table 5. The guidelines were developed by adjusting between 6 area units in the bedroom with the results of anthropometric measurements of the Indonesian elderly. The example of the design can be seen in Figure 1.

Table 5. Standard design for Indonesian elderly' bedroom

Items	Based references	The proposed standard	The related anthropometry data
Entrance	Seo-Ryeung & You-Jin, 2004; Ministry of Public Work of Indonesia, 2006; Rashid, Hussain & Yusuf, 2008	Entrance width should be 95.48cm	elbow span, male 95th
		Door style should be sliding or swing doors.	
		Threshold or sill are not recommended.	
		Door handle height should be no higher than 102.77cm	standing elbow height, female 95th
		Door handle style should be lever type or "D" shape (loop handle).	
Bed area	Ministry of Public Work of Indonesia, 2006 ; Dvouleta & Kanova, 2014	Bed height should be min 36.39cm	(standing elbow height, female 95th).

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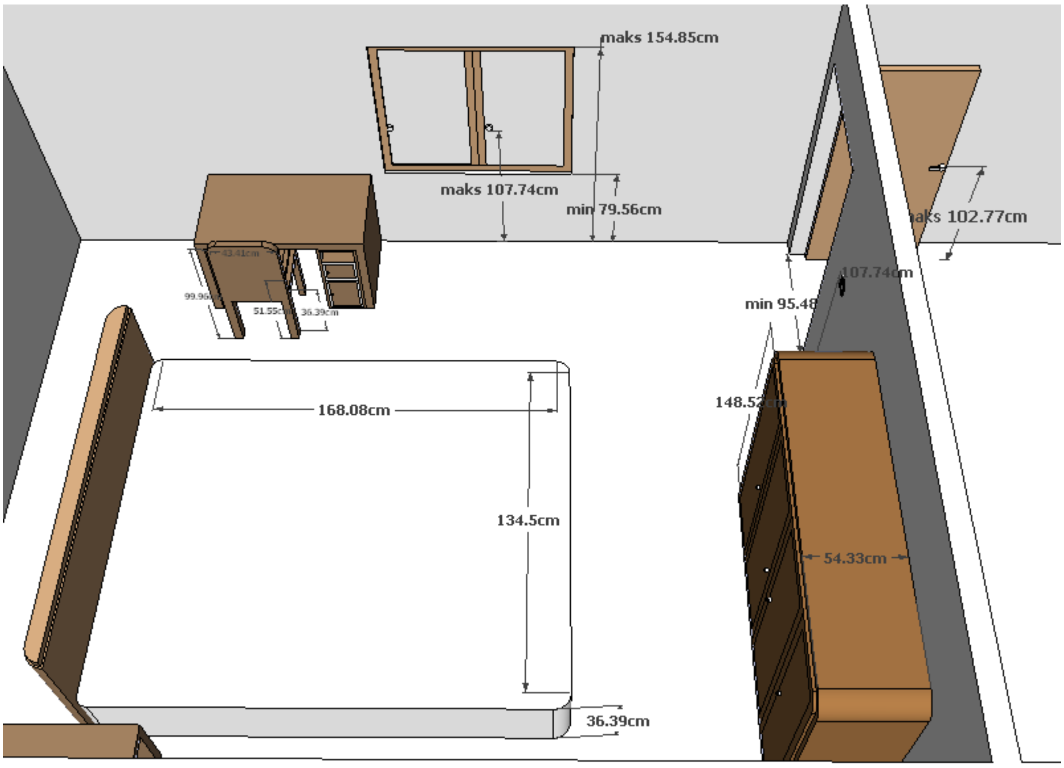
Items	Based references	The proposed standard	The related anthropometry data
Bed area	Dvouleta & Kanova, 2014	Bed size should be 168.08cm in length and should be 134.5cm in width for double bed and 67.25cm for single bed	(stature, male 95th) (elbow span, male 5th).
Storage units	Ministry of Public Work of Indonesia, 2006; Rashid, Hussain & Yusuf, 2008	Wardrobe size should be 148.52cm in height It should be reachable from the wheelchairs.	(standing vertical grip reach, female 5th).
		Wardrobe depth should be 54.33cm	(shoulder-grip length, female 5th).
Work area	Md. Dawal et al., 2015	Chairs should be 36.39cm in height 34.34cm in depth and 39.26cm in width	(sitting popliteal height, female 5th), (buttock-popliteal length, female 5th) (hip breadth, female 95th).
		Chairs should have armrest and backrest feature to accommodate a rest. The backrest feature should be 99.96cm in height above the floors and 43.41cm in width While the armrest feature should be 51.55cm in height above the floors	(sitting shoulder height, female 95th) (shoulder breadth, male 95th). (sitting elbow height, female 5th).
Window area	Rashid, Hussain & Yusuf, 2008	Window height should be max 154.85cm and min 79.56cm	(standing eye height, male 95th) (sitting eye height, female 5th).

Items	Based references	The proposed standard	The related anthropometry data
	Rashid, Hussain & Yusuf, 2008	Window handle height max 107.74cm	(standing shoulder height, female 5th).
Control units	Ministry of Public Work of Indonesia, 2006	Switch or socket height should be max 107.74cm	(standing shoulder height, female 5th).

Figure 1. Example design for Indonesian elderly' bedroom



Conclusion

This study gives contribution in giving pictures of elderly Indonesian lives. The information will be valuable for all shareholder such as Indonesian government or other institutions in order to gain Indonesian elderly independently and to increase Indonesian elderly' well-being, for example through the search of options to overcome the existing problems (e.g., the stress in the nursing home). The anthropometry data of Indonesian elderly is very crucial as a first step in providing a design that compatible with the need of Indonesian elderly. Last, the proposed bedroom design for Indonesian elderly can be seen as a pilot project to standardize other room and facilities for Indonesian elderly. The expected result of the proposed design for the elderly in relation to increasing of elderly' well-being can be applied in other areas in particular in other developing countries.

This study has several limitations. First, the anthropometry dimensions are limited only to 15 dimensions. Although an adequate description of the human body may require over 300 dimensions), the scope of this study was limited to measurement of body dimensions that were considered important for facility design for the elderly, in particular, bedroom design. Second, the number of respondents is limited due to the constraint of the permit in the nursing home. It is encouraged to continue the research about daily activities that support elderly live independently to get a better picture of daily lives of Indonesian elderly, in particular, the study that considers balance number between male and female elderly, as well different age of range of elderly.

Ageing has been recognized as a global issue of increasing importance and has many implications for health care and other areas of policy. Although, it should be highlighted that the issues relatively under-researched, in particular in developing countries. Besides, there is an urgent need for specific policy initiatives at the international level (Lloyd-Sherlock, 2000). Therefore, further research in the elderly must be conducted further particularly considering that generalization cannot be applied since there are different experiences and environment among the elderly in different countries or different area.

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