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Anthropometrical Aspects of a Friendly Rest Room

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Abstract. To give an impression of the aspects involved in the study of body spaces in toilet environment. There are only a few anthropometrical sources about elderly and disabled people. For the purpose of toilet environment this is even rarer. First a new measurement study was prepared within the consortium to fill the gap. But after reconsideration of the time, budget and available human resources the plan was changed in using existing resources in close relation with observational studies. The data from the Geron-project (1993-1998) in Delft have mainly been used as a basic source of raw data. This seemed very relevant for this project and as a next step this knowledge was completed with the quantified usage studies done within the FRR-project in the laboratory at TU Delft but also at a selection of sheltered homes in the Netherlands. To set up an anthropometric study within a consortium of partners in different countries seems only possible if the main goal of the budget is to study anthropometry like in the Caesar-project. If as in this FRR-project anthropometry is only one of the aspects -though an important aspect-within the product development project, then it is better to integrate existing raw data with the results of observational research continuously during the development process.

Keywords. Anthropometry, Toilet Environment, Elderly, Disabled

1. Introduction

Product developers are becoming more and more aware of the importance of applying knowledge about the human body dimensions so called 'anthropometrics' in the early stages of design, in order to make their products better fit to the sizes of their customers. In some products the differences between people, with regards to their body dimensions as well as the behaviour that results from it, have unavoidably been recognized from the beginnings on. For instance in bicycle design; you can buy different sizes for every age, length and even the differences between the sexes are incorporated. In the period 1920-1950 when the popularity of bicycles as a means of personal transport was at its height, women in general wore dresses or skirts [1,2,3]. The bridge in between the saddle and the steering therefore was very hinder some and another construction was made to provide stability without obstructing any dresses and

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skirt-clothing (however this not being the optimal solution; anyone who has ever tried knows about the many other problems with skirt-driving, like getting the fabric stuck in between the pedals or chain, blowing skirts and crawling skirts that go beyond the area one wants to expose in public). Even now one refers to the bike without bridge to as a ‘female-bicycle’ even though trousers are worn by women just as commonly now.

In other products there seems to be hardly any developments with regards to applying anthropometrical knowledge, ever since the first designs were brought on the market. A typical example - and topic of this paper - is our modern water closet. It has stayed with its purely functional design up until now, without taking into account the variations between people. It seems rather strange that a product that is used several times a day and clearly will benefit from fitting to the customer’s body dimensions and behaviour is not available in more variations on the market (see Figure 1). In this particular case the reason probably can be found in the nature of the product; it is attached to the sewer system, which makes a quick change rather cumbersome. The subject of toileting also being a taboo to talk about in public might not help the developments either.

Figure 1. Available variations of toilet bowls in the local D-I-Y store

A first start to change something in toilet design was made though in the EU-funded Friendly Rest Room project. The goal of the project was to come up with a design for the toilet environment and the components in it (toilet bowl, water basin, support bars) that would better fit to the needs of physically more challenged individuals, like elderly and disabled, through taking into account the anthropometrics and behaviour variations in this user group and to combine this knowledge with a ‘smart’ content using the possibilities of building automation.

A part of the FRR project consequently entailed finding and applying the right anthropometric data. In general there can be several reasons why anthropometric data are not being used or used properly in the development of the consumer products:

- Lack of data on the specific type of users or specific dimension (e.g. nationality of the data sample or specific body dimensions of which there are no records)
- Representation of the data is incomplete or leads to reading errors (e.g. tables that only show the P5 and P95 values, while the P1 and P99 values are needed)
- Invalid data (e.g. errors made when measuring, using incorrect or unrepresentative data or when using a small sample size)
- Lack of knowledge to apply the data correctly e.g. in design-teams (e.g. when knowledge level with regards to the human anatomy and/or statistics is not sufficient)

The importance of implementing anthropometrics in product design and the product development process is recognized since long in the curriculum of Industrial Design Engineering at the Delft University of Technology and students are early on taught about it (see also www.dined.nl). Still in practice not all product developers are trained that well in applying anthropometrics[2]. In this paper the Friendly Rest Room project will be used as an example of how anthropometrics were implemented in a practical design problem and the limitations that were faced.

2. Anthropometric Data Resources

In order to design a better fitting toilet for elderly and disabled designers need to know in detail about the specific body dimensions of this group, their dynamic behaviour and preferences that are originating from their capabilities and incapabilities. Thus extensive anthropometric and ergonomic data is needed. In the last 40 years several studies have been carried out and published with regards to the anthropometry of elderly and disabled.

Only some of these studies present real databases on empirical measurements, for example Damon and Stoudt [4], Hobson [5], Wright et al. [6], DIN 33402 [7], Molenbroek [8] and Steenbekkers [9]. Others present overviews, discuss or make estimations for other –unmeasured- variables like Diffrient [10], Kelly and Kroemer [11] and Pheasant [12].

Recently the World Engineering Anthropometry Resource (WEAR) group launched a web-portal to foresee product designers and developers in an overview of anthropometric data sources and an indication of their quality and application domain [13a].

Brown e.a. [13b] and Rogers e.a. [14] conclude that there is a serious lack of data for elderly and disabled that is appropriate for use by designers, particularly dynamic data. Referring to the objectives of the FRR project and the earlier mentioned obstacles in using anthropometric data in the consumer product development, we can conclude that typically 'lack of data on the specific type of users and specific dimensions' is at stake. In general there are not many anthropometric data resources with regards to the population of elderly and disabled. The data resources that are available do not contain

[2] The research program Dynamic Anthropometrics of the section Applied Ergonomics and Design at Faculty Industrial Design Engineering, Delft University of Technology is in the process to develop an ergonomics information system (called EIS) for designers and investigators, which compensates their knowledge in the field of anatomy and statistics, but also compensates their knowledge in the anthropometric design process [15, 16, 17, 18].

much data on dynamic anthropometry measures (like dynamic patterns for support during sitting/rising), let alone specific data on user behaviour around the very sensitive topic of toileting e.g. with regards to cleansing and backward reach.

3. Methods

To solve the lack of appropriate anthropometrical data several methods have been used in the FRR project. We will discuss these methods following the flowchart of the anthropometrical design process in Figure 2.

3.1. Design Process

The flowchart of the anthropometric design process starts with the need for a new design that solves a certain design problem. In the FRR project the objectives were 'to carry out the necessary research and design, the engineering and evaluation of prototypes for a more user friendly rest room for elderly and persons with disabilities'. The general design problem was consequently defined as: 'The elements of the FRR should be able to adjust to the individual needs of older persons with functional limitations or disabilities, allowing them to gain greater autonomy, independence, self-esteem, dignity, safety, improved self-care and therefore enable them to enjoy a better quality of life.'

Research activities and design and development activities took place simultaneously in the project. The research results were translated into a set of design specifications gradually building up during the course of the project. Product ideas and design concepts were developed based on these growing design specifications. Several successive FRR prototype generations were tested at 5 European test sites, the so called User Research Bases (URBs). In these URBs the FRR prototypes or parts of the prototypes were tested by in total more than 230 test persons from the target group elderly and disabled.

It was set at the beginning of the project that it would not be feasible to come up with a fully market ready prototype of a Friendly Rest Room within the project's boundaries of time and budget. The final design therefore is equivalent to the last generation test prototypes. Findings of the user tests would serve as a basis for further developments of user friendly rest room products and disseminated as such.

3.2. Static Anthropometry: Defining the Target Group

The target group of the FRR consists of elderly and people with disabilities. Though differences in behaviour and preferences are without doubt to be expected, no specific differentiation was made in gender; men and women were equally subject of study. With regards to ethnicity and type of disability initially no distinction was made either.

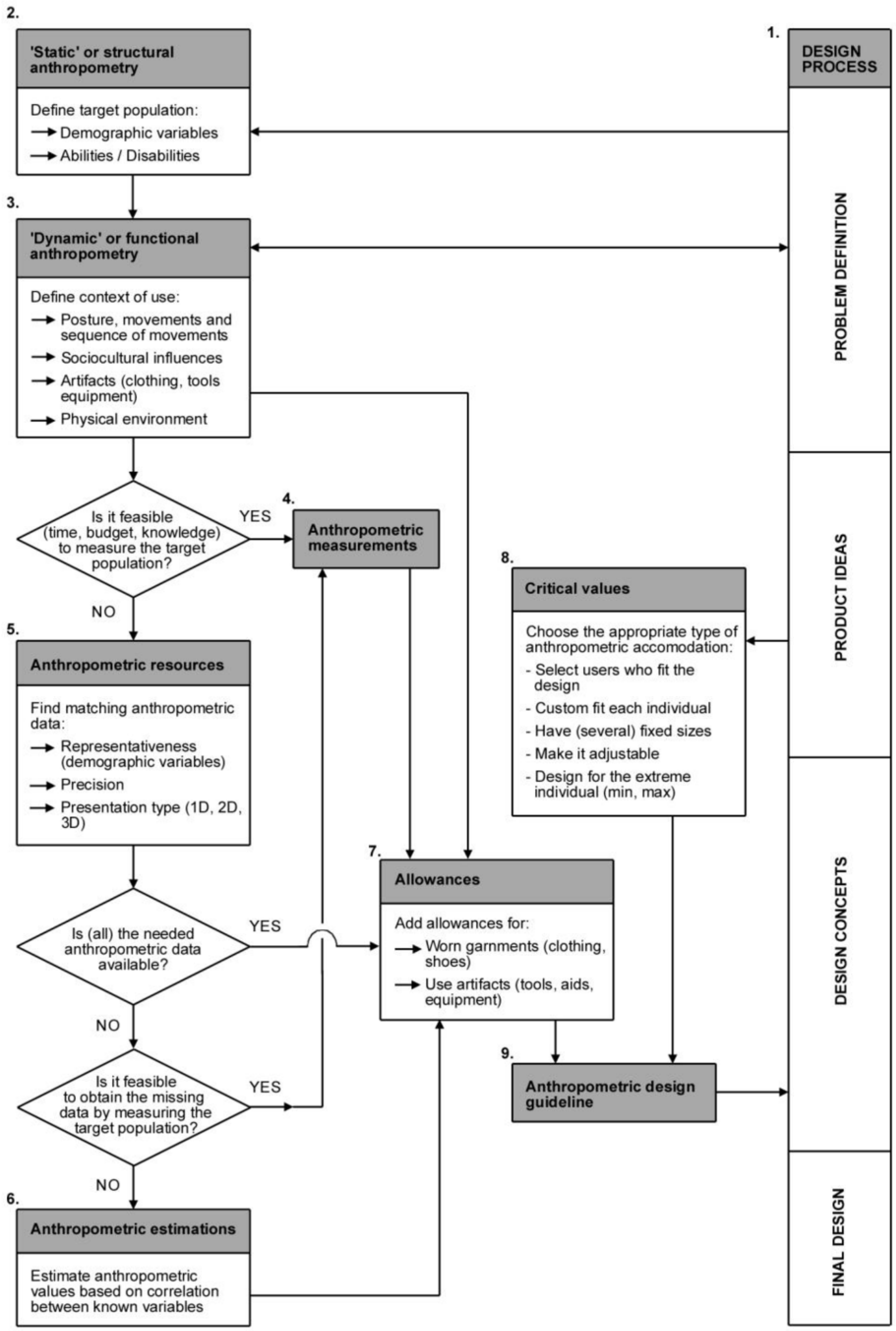


Figure 2. Flowchart of the anthropometric design process

This resulted in a fairly large and inhomogeneous target group, which made designing a rest room that would fit every individual in this target group a very difficult task, but also would simply be a too elaborate job for this project. As a compromise it was proposed to design for typological sample groups, categorised according to their limitation (see table 1), and let representatives of these groups test the successive FRR prototypes.

Our ideal sample would have had an equal part of all the disabilities to be expected in the population of elderly and disabled and should have covered the extreme anthropometric values on the relevant design-variables. Yet the typological samples according to limitation made the designers really focus on the limitations that resulted from the disability, rather than focusing on a specific type of disease or disability. In this way it was easier for them to depict the effect of their design decisions; whom they had not accounted (enough) for or even made things more difficult for.

The minimum number of test persons per homogenous group was set on 5, based on the studies by Kanis[19,20]. In these studies it was found that, when testing for use problems in consumer goods, the majority of problems are in many cases found by the first 5 test persons and that the 6th and further test persons do not essentially contribute after this to the already found list of problems.

Table 1. Typological sample groups according to limitation

Categories by limitation		**Number of test persons**	
		Male	*Female*
1	Limitation of walking	n = 5	n = 5
2	Limitation of sitting / rising (dynamic)	n = 5	n = 5
3	Limitation of sitting / standing (static)	n = 5	n = 5
4	Limitation in use of arms or hands	n = 5	n = 5
5	Limitation in movement resulting from a disorder in balance	n = 5	n = 5
6	Limitation in the senses (vision, hearing, smell, touch)	n = 5	n = 5
7	Limitation in movement of the torso	n = 5	n = 5
8	Limitation in the mind / memory	n = 5	n = 5
	Total	n = 40	n = 40

In practice the successive prototypes were eventually tested by 230 test persons in total. The test person selection however had not been done following the structure from table 1, but was done according to the availability of test persons at the different test locations (URBs). Each URB focused on the typological sample groups they were in practice most close to, e.g. through former studies, experience or contacts. URB Lund therefore mainly tested limitation in vision and limitation of walking. URB Vienna gathered their test persons through the MS Society, and therefore tested limitations of walking, sitting/rising and use of arms or hands. URB Athens tested with both elderly

and disabled and therefore did not focus specifically on certain limitations, but more or less covered them all.
Cultural coverage and differences in ethnicity were covered as well, because every URB gathered their test persons geographically not far from their test location, which consequently resulted in a Swedish, Austrian and Greek sample.

3.3. Dynamic Anthropometry: Defining User Behaviour in order to Find the Relevant Variables

The next step in the anthropometric design process is to analyse the context of use. Goal of this analysis is to determine which anthropometric variables are relevant to the design. The analysis entails studying posture, movements and the sequence of movements. In toilet design one wants to know for instance about toilet rituals and the manual handling that has to be done. Especially in elderly individuals who have balance problems it turned out that the turning movements near the toilet, undressing/dressing and sitting/standing are experienced as cumbersome[21,22].

In order to find out more about the context of use in elderly and disabled – around this very sensitive topic of toileting – several explorative studies were performed. In these studies also the influences of socio-cultural differences, the use and handling of artefacts in the toilet area (clothing, tools, equipment) and the influence of the physical environment on the context of use were studied.

First a visit to a home for elderly was made to explore the settings of the toilet facilities offered here and the common problems that were experiences, both by staff as elderly habitants themselves (see Figure 3). Addressing the problem elderly people have with the fixed height of standard Dutch toilets, next an explorative study into toilet heights and toilet raisers was performed [21]. In this study 15 elderly were interviewed about their toilet facility and a video was made of how they moved from their living area to their toilet area and sat/rose from their toilet (clothing on, see Figure 4). The results from these explorative studies showed that as one gets older more problems are experienced with sitting/rising from the toilet, with cleansing of body parts and the lack of proper (non-stigmatising) support for these activities.

In order to find more about the exact needs for support during sitting/rising from the toilet and cleansing, a more controlled laboratory study was performed with 9 healthy elderly women and 6 healthy elderly man (see Figure 5) [23, 24]. Additionally a master thesis study [25] was performed on reducing the fall risks for elderly in the restroom and an innovative design for non-stigmatising toilet support bars was made [26, 27]. The results of both studies are described more elaborately in this volume as well [28, 29].

Figure 3. Visiting a sheltered home for elderly (Ede, NL)

Figure 4. Visiting elderly in their homes (Delft, NL)

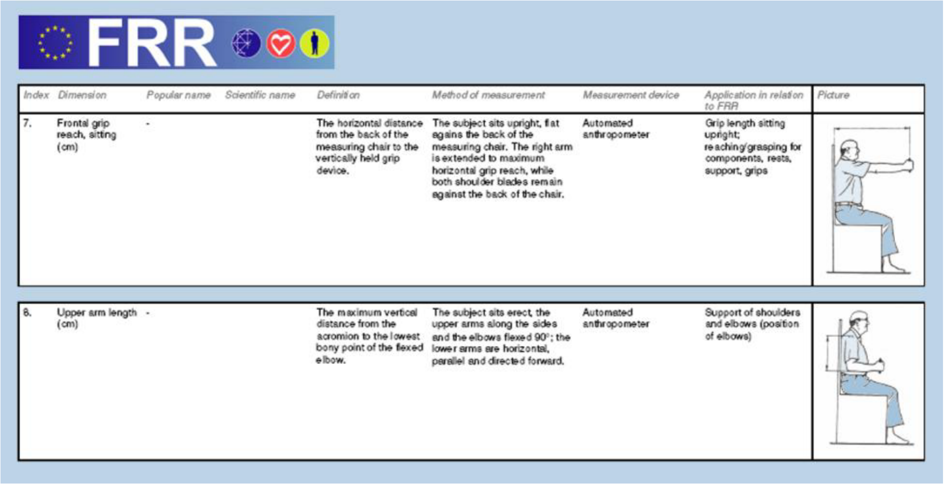
Figure 5. Laboratory test environment to determine the location for support around the toilet (Delft, NL)

3.4. Anthropometric Measurements and Anthropometric Resources

After defining the target group and having analysed the context of use now a list of anthropometric variables relevant to the design of a toilet for elderly and disabled was available. Next step was to decide how to translate this list in a set of exact design specifications. These design specifications should enable all intended users of the toilet to use it effectively and efficiently, and not be limited by their size.

The question was whether to perform the necessary anthropometrical measurements ourselves, or to look for appropriate anthropometrical data resources? In the FRR project it was decided to use an already available and fairly recent large anthropometrical data set on Dutch elderly (GDVV, measured in 1982 and Delft GERON-project, measured in 1993-1998) [8,9,30] and retrieve any other unknown data by measuring small user groups. In this way -amongst others- the difference between elderly from Greece and Sweden in comparison to Dutch elderly was retrieved, which resulted in a lowering of the minimum of the height adjustability.

For measuring the small groups of elderly and disabled in the URBs, an anthropometrical measurement protocol was written and measurement chairs were built (see Figure 6 and 7).



FRR

Index	Dimension	Popular name	Scientific name	Definition	Method of measurement	Measurement device	Application in relation to FRR	Picture
7.	Frontal grip reach, sitting (cm)	-		The horizontal distance from the back of the measuring chair to the vertically held grip device.	The subject sits upright, flat agains the back of the measuring chair. The right arm is extended to maximum horizontal grip reach, while both shoulder blades remain against the back of the chair.	Automated anthropometer	Grip length sitting upright; reaching/grasping for components, rests, support, grips	
8.	Upper arm length (cm)	-		The maximum vertical distance from the acromion to the lowest bony point of the flexed elbow.	The subject sits erect, the upper arms along the sides and the elbows flexed 90°; the lower arms are horizontal, parallel and directed forward.	Automated anthropometer	Support of shoulders and elbows (position of elbows)	

Figure 6. Detail of the anthropometrical measurement protocol used in the FRR project

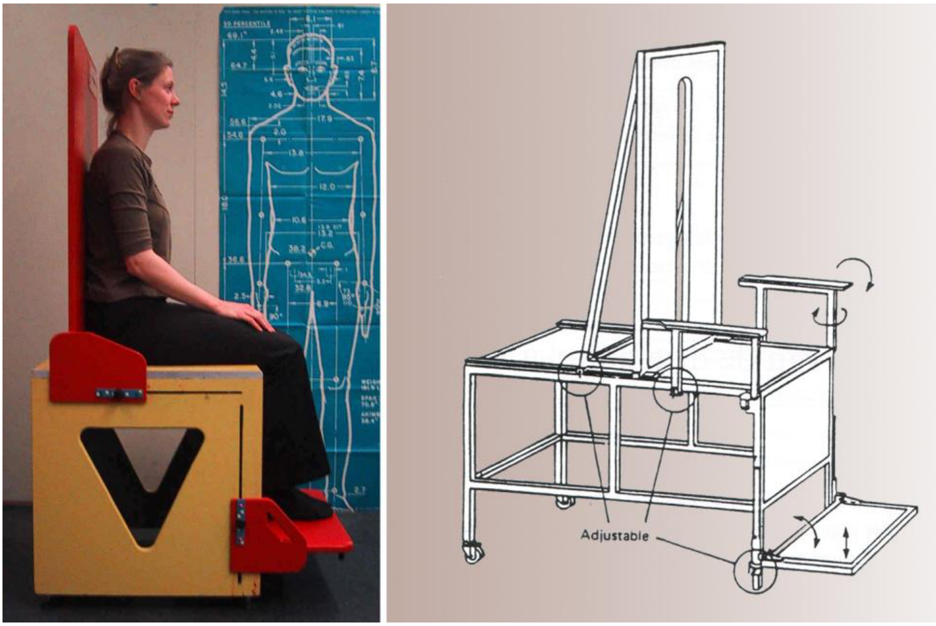


Figure 7. Two anthropometrics measurement chairs

Table 2. Six relevant anthropometric dimensions for using a toilet (data from Molenbroek [8])

P1 (mm)	P99 (mm)	User variables	Additional variables	Product variables
429	583	Buttock-popliteal depth	- Ca.50 mm (for rising from toilet seat)	Toilet seat depth
344	516	Popliteal height	+ Heel height (for public use) - Thickness toilet seat	Toilet seat height (adjustability range)
316	454	Hip breadth		Toilet seat width Distance between horizontal support bars (adjustability range)
177	299	Elbow height bended while seated		Height horizontal support bars (adjustability range)
690	1010	Reach depth envelope measured from back to grip		Forward reach distance vertical support Location handles vertical support
40kg	120kg	Body weight in kg		Strength of toilet and support construction Thickness toilet seat

3.5. Anthropometric Estimations

The anthropometric data set on Dutch elderly that was used in the FRR project was used to determine the needed dimensions of the new toilet design. A transformation table was used to estimate the design specifications from the sitting measurements presented in this dataset (see table 2). A similar table was used in a former study of Molenbroek to determine the right dimensions of a wheelchair design [31].

3.6. Allowances

In any other product normally it is necessary to add allowances for clothing and shoes. In toilet design the influence of clothing is obviously not direct, since one uses the toilet bare skinned, but there is an indirect influence though. Particularly in the (semi-) public toilet environment one does not want the undressed clothing to fall onto (filthy) floors, which results in all kinds of strategic cloth handling positions, while performing the normal sitting/cleansing/rising activities. One can imagine that having to hold on to clothing limits the amount of comfortable body positions and can seriously lead to fall-risky situations. This problem is less serious in the 'clean' home environment, but still it is true that handling of cloths effects the way people act in the toilet area (see also Figure 8).

Since in a home environment people use the toilet without their shoes on, but in (semi-)public environment they will definitely wear shoes, it was decided to design for both situations and adjust the range of height adjustability accordingly (see also table 2).

Figure 8. Balancing and handling of cloths during toilet use

3.7. Critical Values

Last but not least in the design process a decision has to be taken about the way the anthropometrics of the target group is dealt with. In other words, the choice for a certain type of anthropometric accommodation will result in critical values of product dimensioning. The following list will explain each type of accommodation and gives an example with regards to (current) toilet design solutions:

- Select users who fit the design; The standard height of a toilet bowl –fixed to the floor- is 40 cm. This height is based on the assumption that the general popliteal height is about this height. However there are many people for whom this height is too low, and others for whom it is too high. Even though most of these people can use the toilet nevertheless, it can be rather uncomfortable with folded legs, or even risk full when your feet are not touching the ground. In current toilet design you can conclude that nothing special is done to fit the product to its user; the user will simply have to fit or otherwise has to search for salvation elsewhere.
- Custom fit each individual; A so called 'freely hanging' toilet bowl can be positioned and installed according to your own personal needs. When in a family for instance, more than one individual is to use the toilet and his family members differ much in length for example, the problem is not solved unfortunately.
- Have several fixed sizes; In the market there are several types of toilet seat raisers. These extra high toilet seats can solve the problem that one family member needs a higher than standard toilet and the other family members do not. Toilet seat raisers are not an optimal solution though, because they often show problems with stability (or perception of stability) and hygienic issues (difficult to remove easily and clean). In addition to this they do not offer a solution to the individuals who are in need of a lower than standard toilet bowl.
- Make it adjustable; In the FRR project this solution was chosen for the final toilet design. The 'freely hanging' toilet bowl was adjustable in height and operated with a handheld control. Also a solution for the sitting/rising problems elderly face was offered, through the extra option of tilting the bowl.
- Design for the extreme individual: In the FRR project this solution was in fact chosen as well because the range of height adjustability of the toilet bowl was determined by the anthropometric of the smallest Greek test person and the tallest Dutch test person.

3.8. Design Guideline

The outcome of all the different phases in the anthropometric design process can finally be put into an anthropometric design guideline. In the FRR project this design guideline gradually was built up while going through the successive stages of prototype testing and user behaviour studies.

4. Results

The anthropometric design guideline was used on several moments within the design process. It was crucial to have short and frequent communication between the designers and the anthropometric specialist and the anthropometric knowledge transfer was especially important in the development of the following parts of the FRR:

- The height and sizes of a patented door handle: it should be comfortable to be reached and gripped by elderly persons as well as wheelchair users.
- The shape, size and height of a wall mounted grab bar.

- The range of the height and angle of the toilet bowl in- and excluding seat; it was discussed that the highest position, when sloped at maximum, also could be used as a urinal for men while standing.
- The size and the shape of the seat in close relation with the transfer-seat
- The range of the width and height of the horizontal and vertical grab bars. This described in more detail in the chapters from Dekker and Buzink [29].
- The range in vertical and horizontal position of the wash basin. Also more elaborately described in Dekker and Buzink [29].

5. Conclusions

In the FRR project anthropometry has been tightly woven trough the design process and apart from a good communication between designers and researchers, it also requires the availability of a lot of data and -if not available- the ability to perform user studies with a small sample to find out which measurements are relevant. When no data exists on the relevant body dimensions, these will have to be measured in short time in an effective and efficient way.

To set up an anthropometric study within a consortium of partners in different countries seems only possible if the main goal of the budget is to study anthropometry like for instance this is the case in the Caesar-project [32]. If as in this FRR-project anthropometry is only one of the many important aspects within a product development project, then it is often better to integrate existing raw data with the results of observational research continuously during the development process.

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