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THE INVESTIGATION AND COMPUTER MODELLING OF HUMANS WITH DISABILITIES

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ABSTRACT

Aids for the invalid or infirmed are often created simply by modifying those used by the able-bodied, with little care taken as to their individual needs and limitations. This study is aimed at determining their actual requirements through both modelling their anthropomorphic conditions, and measuring their physical capabilities.

The subjects are evaluated in an experimental rig where, for example, the appropriate force data is collected. The physical limitations of the skeleton are also recorded and entered into a manikin model incorporated within a constraint environment. Together the manikin models are used to evaluate the disability aid under consideration.

This approach has been employed in the study of wheelchairs for people with spinal injuries. Here the positions at which the maximum pushing capability of the subject can be determined and the chair modified, or redesigned, to allow this to be achieved. A similar approach can be applied to other invalid aids and medical equipment.

A procedure is now being developed that can be applied to the collection of this data which can handle a range of problems for the creation of more effective aids for the elderly and infirmed.

Keywords: anthropomorphic, human measurements, constraint modelling, invalid aids

1 OBJECTIVE OF STUDY

In order to design aids for invalids and the infirm it is important to fully understand their capabilities and needs. Many of the current devices have been provided through the modification, or adaptation, of existing designs used by the able-bodied user. Very little work has been carried out into the fundamental needs of this group of subjects and their ergonomic capabilities. Similarly, the majority of human modelling techniques offer only the capabilities of the able-bodied and ignore those with extreme and critical disabilities.

The current research study has set out to provide this information within a combined investigation that includes both experimental and analytical techniques [1]. The capabilities of the individual subjects are studied through experimental procedures, and computer modelling used to allow chosen tasks to be determined and resolved, which allow realistic body postures to be developed [2]. The resulting posture and strengths then provide the basis for the device redesigns.

2 EXPERIMENTAL PROGRAMME

The major experimental investigation has been (and continues to be) conducted in collaboration with the University of Canterbury, in New Zealand. Within the Department of Mechanical Engineering, they have been creating experimental techniques and rigs to allow postures and forces to be measured on the handicapped [3]. This is currently directed towards the study of tetraplegics through Burwood Hospital, which is the national centre for spinal injuries (and through which they obtain ethical approval). This work is undertaken with real subjects and through this process, of modelling their problems, improvements are sought in their living conditions.

The effort to date has centred on mapping the strength capabilities of wheelchair users. Here an experimental rig has been developed in which the forces created, whilst pushing, can be measured for different sitting and hand positions (figure 1.).

Figure 1. Experimental wheelchair pushing rig.

Investigations undertaken on a range of subjects have shown that their capabilities are highly dependent on both the level of spinal injury and the position at which they are able to apply the force. The position of this point of application, and its movement across the drive wheel rim, results in considerably different forces over small changes in pushing position, as can be seen in the force mapping in Figure 2.

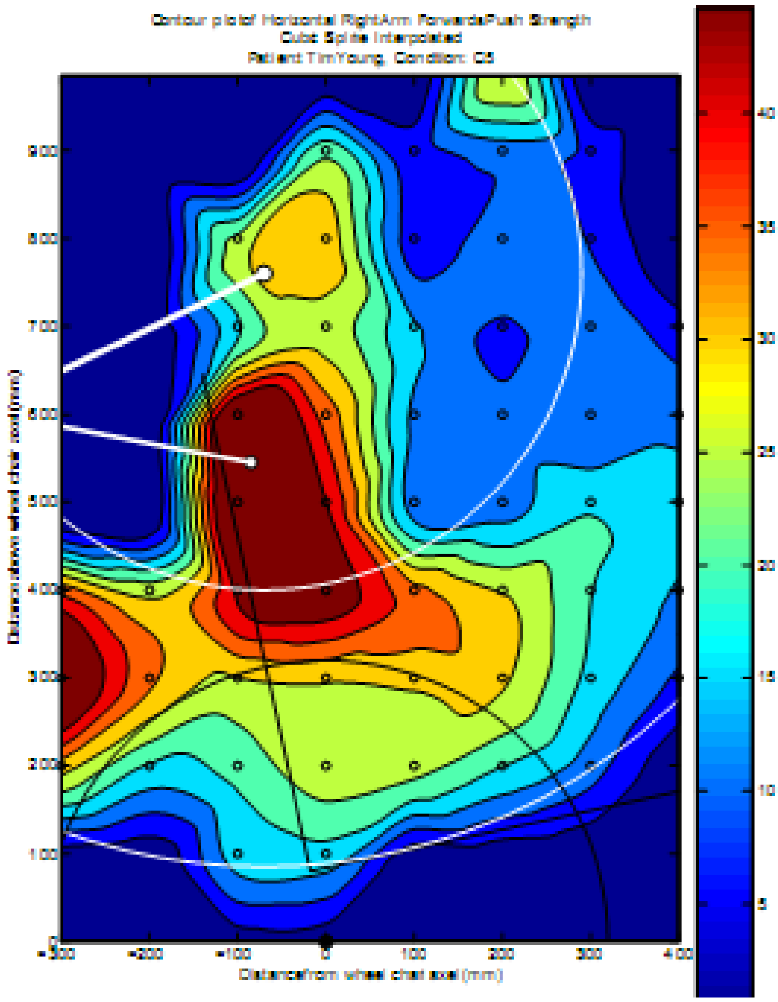

Figure 2. . Force map created from experimental data for an individual subject, showing the variation in forces with reach capability.

The rig has been designed to allow it to be adapted to provide data on other studies that can range from working across a surface to that of direct lifting by the subject. As problems are proposed and investigated, a number of force mapping experiments will be conducted for a range of individuals. This will provide the basis of a library of mappings that can be used to compare capabilities and to provide information upon which other devices can be considered and redesigned.

3 ERGONOMIC DATA

In such studies of human posture it is necessary to understand and incorporate the ergonomic limitations of the human body. This has been achieved through collaborative work with Professor Johan Molenbroek at the Technical University of Delft [4]. Within the Department of Ergonomics and Design, data has been collected over the last twenty years on a large group of humans, covering ages from a few months old, to males and females in their eighties. This range of data has been made available to the research together with their ADAPS anthropomorphic computer representation [5]. Since being incorporated into the University of Bath research programme the Delft manikin has been extensively modified and adapted to allow closer human movements to be represented that are necessary for the study of invalids (these include, amongst other things, the ability to balance, a more complex three segment spine model and the modelling of hands with the ability to grip [6]).

4 COMPUTER REPRESENTATION

The resolution of a desired posture or task can present a difficult and uncertain problem. The variables involved in the solution of any task can vary from simply the movement of, say, the eyes in looking at an object, through to, perhaps, 50 or more when the same looking activity is required and the object to be ‘seen’ is perhaps behind the manikin, thus requiring complete body motion and the selection of a new posture.

The approach adopted in this study has been based upon that of a constraint resolution approach developed by the Bath research group over the past fifteen years [7]. Here the problem to be solved is described by a collection of ‘rules’ that are tested against the total truth of all the rules of the problem. Direct search techniques are used to search for a combination of variable values that make the problem true. When used in the design of mechanical systems (such as packaging machines) all of the rules can be determined and the variables known [8]. Within the modelling of humans, it was necessary to create an approach using sensitivity analysis in which the variables influencing the solution could be found and ranked [9]. This allowed the variables to be increased and changed during the course of the investigation.

5 APPLICATION OF APPROACH

During the development of these techniques a number of human studies have been undertaken both to provide a greater understanding of the type of human problems that can be addressed, and to provide an increasing confidence on the experimental and computational techniques being created.

These studies have concentrated on differing aspect of the problem and have included the following:

1. Individual studies of human actions such as balancing, pointing, looking and gripping (both individually and in combinations).
2. Stair climbing.
3. Working at an ironing board.
4. Sitting in, and propelling, a wheelchair.

With further development and refinement of the approach, the method can be applied to a wider range of problems.

6 MODELLING CAPABILITY

The capability to model a wide range of human problems and limitations depends on the creation of a generic modelling environment with high flexibility and control.

The constraint modeller has been created with a hierarchical modelling structure that allows embedded capabilities. Any desired level of space can be embedded within another to provide both simple embedding and pivoting. This, together with the built-in nine degrees-of-freedom of the individual spaces (3 of translation, 3 of rotation and additionally 3 of scale) provide a very large number of freedoms that can be applied to the solution.

Such numbers of freedom are often beyond the normal requirement, and so within the environment each can be either ‘fix’ or ‘freed’. The fixing/freeing can be either defined in the definition of the problem, or the effect of the variables can be determined dynamically, during the problem progression, by sensitivity analysis. Those having no, or very little, influence on the problem can be ‘fixed’ during individual activities and reinstated later.

The range of values allowed in each freedom of human motion is not unlimited, as joints can not continuously rotate, as in machines. The direct search technique used incorporates limit checking techniques. If the search tries to move the motion beyond a limit that is specified then the chosen freedom is reset to the defined limit and the search continued without that variable.

The range of limits, both upper and lower, can be set and selected from a number of data files. They can represent the extremes of human movement, the normal range, the ‘socially acceptable’, or even tailored to the capability of an individual.

6.1 Obtaining Individual Capabilities

With this wide range of modelling capability the human model can be adapted to represent a subject that extends from that of a full range of human capabilities through to one of severe disabilities. In order to capture such a range a program has been developed that can be employed by the occupational clinician to observe and record approximate data of postures and deformability. Here the proposal is to follow their normal approach of estimating the subject’s postures in chosen position, and passing this data directly into the graphic generating programme. This can then be compared to the subject from different viewing positions and when the different postures are adopted.

The modelling environment commences with normal human geometry and limitations (figure 3). These can then be modified, using constraint rules to provide a representation, such as a paraplegic sitting in a wheelchair (figure 4) .Here rules provide, and determine, the sitting posture that results from the needs to contact the various parts of the chair and to undertake other actions such a looking and reaching the drive wheels. In previous paraplegic studies[10] the postures taken by different spinal injuries were seen to be quite different due to the level of the injuries as can be seen in Figure 5. and required additional rules to represent each condition.

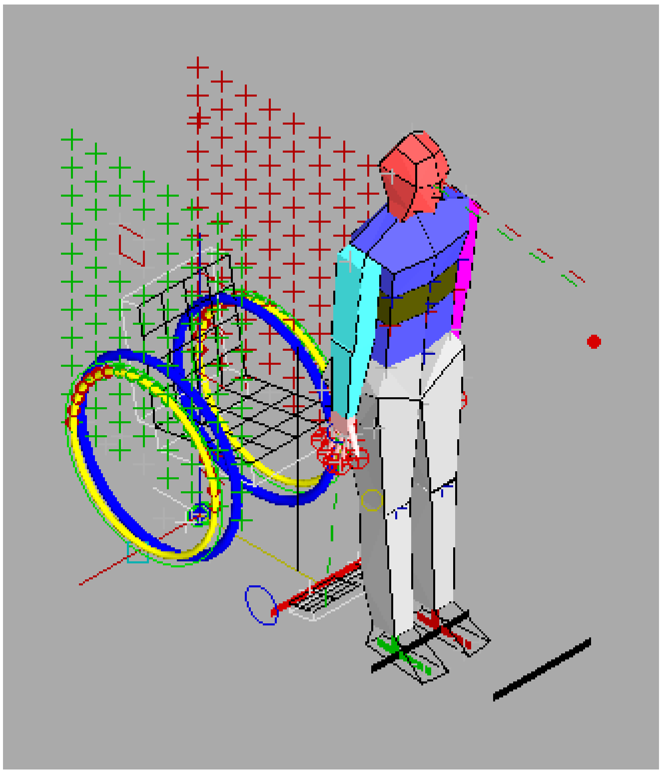

Figure3. Manikin in normal standing posture in front of wheelchair.

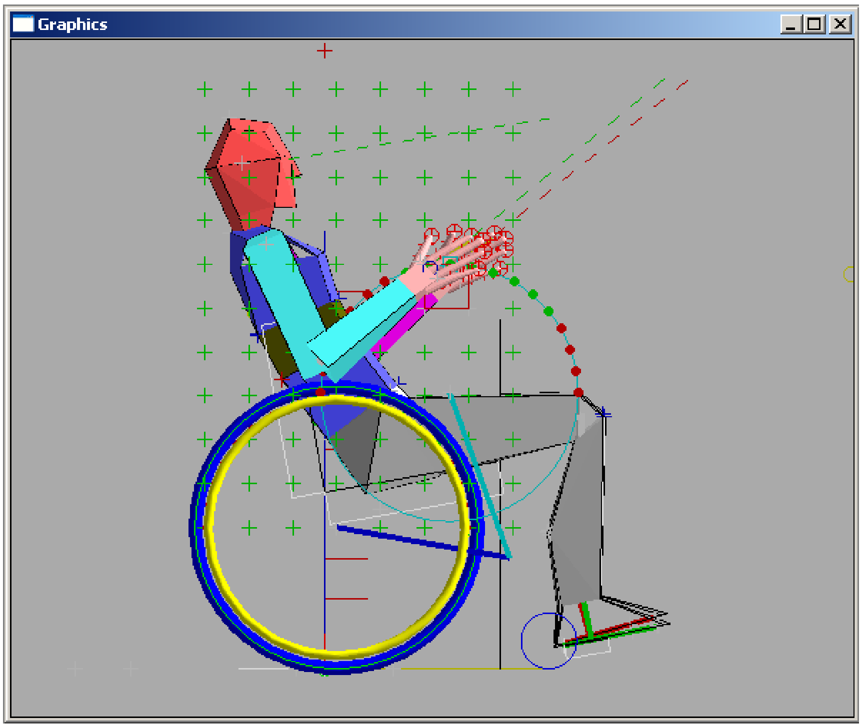

Figure 4. Manikin complying to rules of sitting in wheelchair, looking and operating it.

Figure 5. Different postures undertaken by L1 and C6 subjects when of sitting in a wheelchair.

The capability of the constraint modelling environment allows the standard manikin to be readily modified. At the first level the model can be parametrically changed by the insertion of different geometric values to represent the skeleton. With the ADAPS programs, obtained from Delft, at least twelve body sizes were provided that ranged from a 3 month old baby to 80 year old males and females. Individual models can also be made of chosen subjects.

In the study of invalids it is necessary to model both truncated and lost limbs. These are achieved by manipulation of the embedded scale parameters available in each model space, which can be reflected through the embedding function down the complete limb hierarchy. Figures 6 and 7 show representations of both the loss of a right leg below the knee and a person with stunted lower legs.

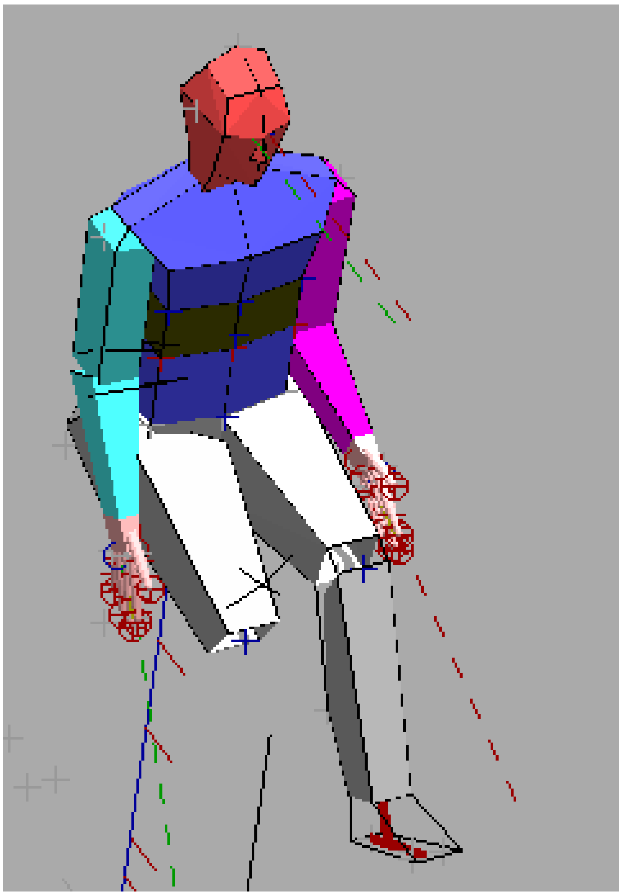

Figure 6. Model with the loss of a lower right leg

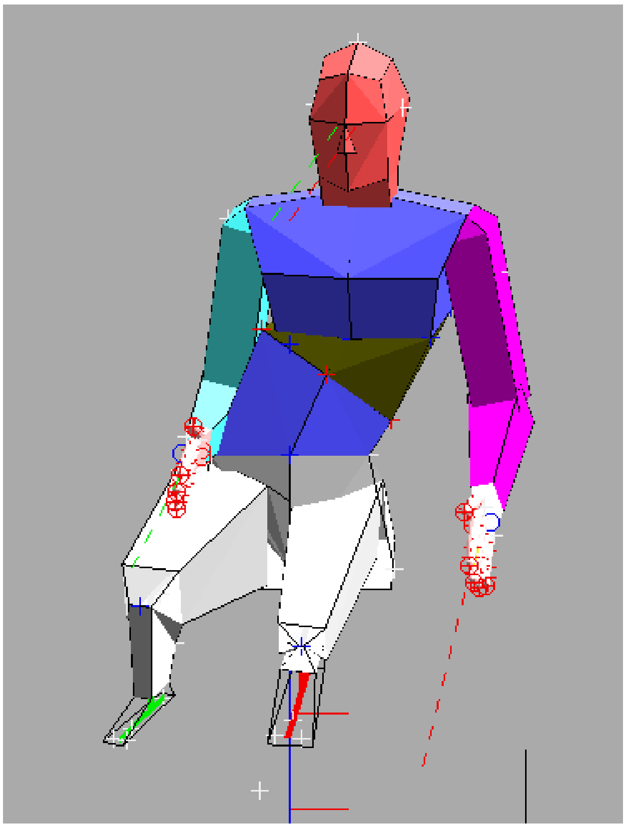

Figure 7. A representation of a subject with stunted lower legs and twisted spine

Further manipulation of the body geometry allows the distortions resulting from a range of illnesses to be modelled, as with the twisted spine (also shown in Figure 7). Here the manikin model has been reduced to a three segment spine as the full spine representation is difficult to create and for which it is not easy to obtain accurate data for all segments by observation.

7 DESIGN MODELLING APPROACH

The purpose of this study is to create an integrated environment in which it is possible to collect the data necessary to both analyse and design invalid aids, and support devices, for the handicapped. The approach is centred on the integration of determining the force capabilities of the individual in the desired posture necessary to undertake the task required. It is also necessary to determine what modifications will be made to those postures as the result of their illness. Once these are understood then designs can then be proposed and evaluated, as has already been undertaken in the repositioning of the driving force actions in the wheelchair, to align with the subject’s maximum force profile.

7.1. Experimental data rig

The experimental rig needs to be very flexible to allow force measurements to be taken in any desired position and for any posture. This must include from the normal sitting positions through to those of standing, lying down and, possibly, of working at a desk. For these reasons the rig has been generated as a space frame in which the attitudes and activities can be set up and undertaken. The force data is collected at selected points throughout the space and transferred into the manikin modelling program, where it is mapped into the appropriate surfaces.

7.2. Individual anthropomorphic data collection

The limitation of the individual human subject needs to be collected and evaluated by professional medical staff. The approach being adopted is to create a modelling environment that allows them to follow, as closely as possible, their normal procedures in evaluating a subject. This approach uses a simple assessment form on which all limitations are recorded. If a posture is being assessed the angles and distortions observed are recorded on the sheet (either as estimated angle values or as ‘+’ or ’-‘). These are then combined and postures estimated in further analysis.

The approach currently being investigated in the prototype system is illustrated in Figure 8. Here the various data collected is used to manipulate the manikin model directly. The effect of these distortions can be readily observed and corrections made, if necessary. The representation of the complete human subject can then be recorded and filed upon the computer system.

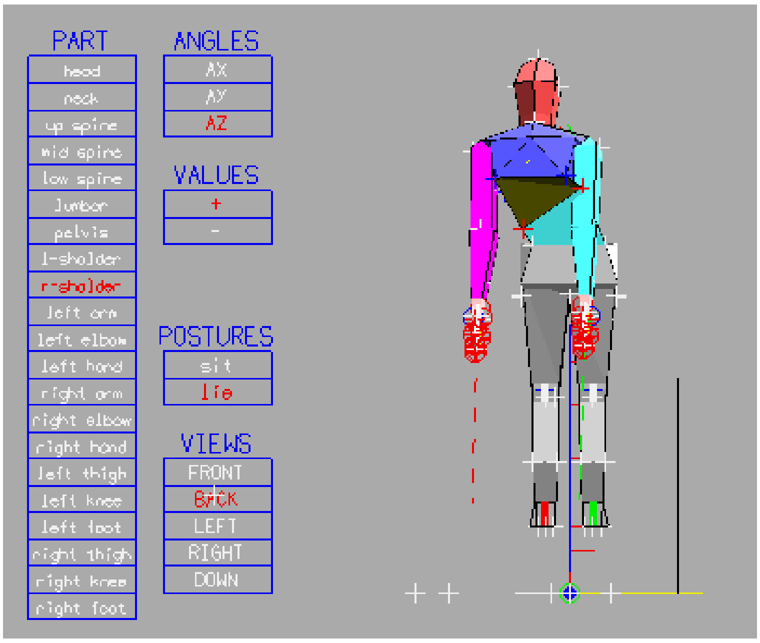

Figure 8. Data entry prototype for the collection of posture limitations

This data collection can then be repeated, if necessary, with the subject in other postures, such as sitting or lying. The results can then be compared and conflicts between observations resolved. In Figure 9 a resulting sitting posture is represented which can be checked and modified by observing it from different view positions.

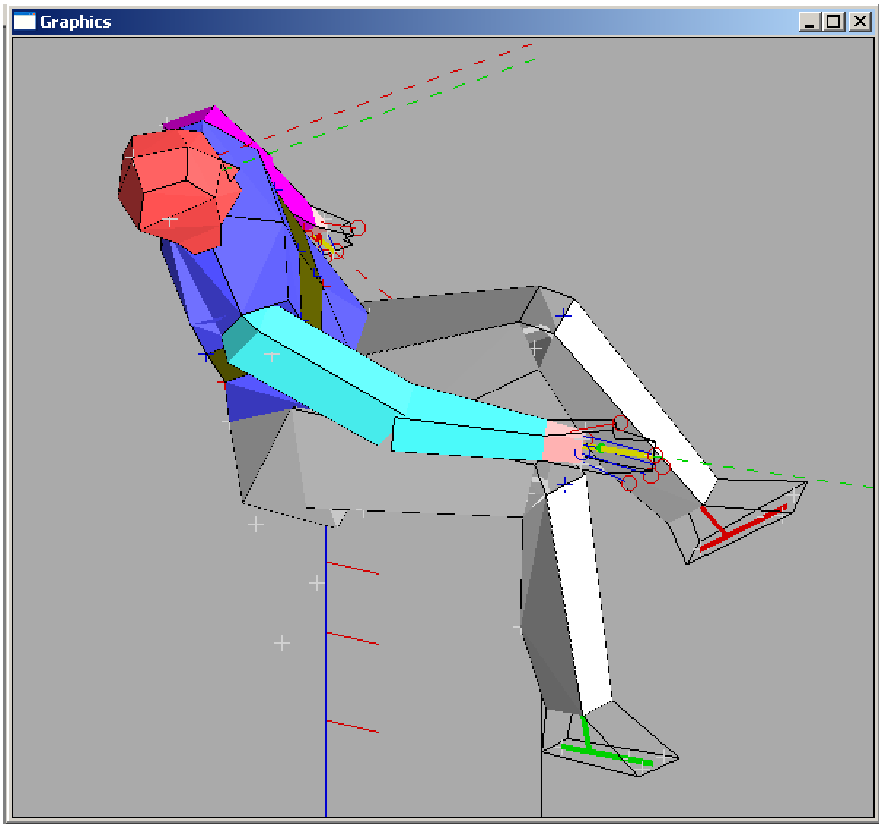

Figure 9.Resulting sitting posture of subject.

7.3. Design studies

This information, on both force capability and limitations in posture, thus provides the basis for any design study. Any successful design must not exceed the force and physical capabilities of the subject who is going to use it. The data thus collected can be used in the evaluation of proposed designs and alternatives sought. Within the constraint modelling environment optimisation and direct search procedures can be used to allow the parameters of a proposed design to be manipulated is search of a solution that satisfies all the desired conditions that need to be satisfied.

8 FUTURE WORK

This paper provides the background to the preliminary study undertaken of the approach being adopted for the design of invalid aids. The work so far has shown its feasibility, and has led the authors to investigate the possibilities of funding a full research project into this subject. The success of the full research activity is now dependent upon undertaking further case studies, such as the current wheelchair redesign, which will provide the evidence and support for such an approach.

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