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A Technical Note

Computer-aided design in wheelchair seating

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Abstract—This paper describes the integration of computer-aided design (CAD) with the design and fabrication of wheelchair seats. The use of CAD during the design phase permits personal seating for adult and pediatric clientele through a series of standard manufactured seating components.

The advent of CAD has permitted the creation of databases of detailed 3-D wheelchair structures that are commercially available, in addition to most standard modular seating components. Direct on-screen manipulation of these components on any selected wheelchair structure is through user-friendly software.

When using CAD, structural and physical limitations can be foreseen and taken into consideration during the routine initial fitting on an adjustable simulation fitting chair. The end product is a dimensioned drawing of the seating arrangement as it is positioned in the wheelchair structure. The seating components are manufactured from this drawing.

The CAD system permits seating specialists to simulate a client's seating arrangement on the wheelchair in order to determine a functional position before the fabrication phase. Essentially, the CAD software is used as a simulation tool for creating functional seating units. It is also a design tool that allows access through a database to dimensional information about commercial seating products and seating products developed through the use of the CAD system.

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INTRODUCTION

During the past ten years, there has been a surge of interest in the field of adaptive seating for wheelchair users. Adaptive seating is a postural aid used to compensate for skeletal weaknesses or deformities which can limit an individual confined to a wheelchair. This type of seating may be the most important device for a client who cannot be comfortably and safely seated in a standard commercial wheelchair (18).

Developing the seating arrangement is not an easy task. The objective is to provide optimum comfort while halting progression of or accommodating deformities. To this end, a thorough evaluation of the client's needs must be undertaken (17). It should include physical aspects, functionality, and the psychological dimension (11). In addition, good posture encouraged by proper seating will improve digestion and respiration and minimize the risk of pressure sores (7,10).

Function is another important facet of proper seating. Maximum independence during activities of daily living must be properly assessed and encouraged. A seating arrangement should allow the versatility of transferring from one wheelchair to another (4). Finally, overall good posture will permit

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better appreciation of one's self image, thus increasing self-esteem and confidence. As a whole, this will encourage integration and participation in social activities and, in general, society (1).

The importance of proper seating equipment to attain these goals is well-recognized within the rehabilitation community. To insure proper seating, four aspects to be considered: 1) an adequate shape reproduction of the back and the seat; 2) a proper location of armrests, footrests, and back and seat angle; 3) choice of an adequate wheelchair base; and, 4) proper location of the seating system on the wheelchair base. The last three aspects must be properly addressed to ensure function and mobility in the environment.

Today, there is an impressive number of commercial seating systems available (3,5,8,9,12,14, 15,16). Most claim to be efficient methods for body contour seating systems. However, contour is only one aspect of proper seating. It is one thing to create a seating unit that is comfortable and that conforms to body contours, but it is another matter to emplace a seating unit on a wheelchair structure in a way that it is functional and practical for the patient during daily activities. The authors believe that not enough attention has been given to the important aspect of installing a seating unit on a wheelchair structure. This important point is discussed in detail in the designing components section of this paper.

METHOD

Overview

A team of prosthetists and technicians created a technique to address each client's contour requirements when designing wheelchair seating (2). The method allows personalized seating through standard seating components. The technique caters to adults and pediatric clientele that have cerebral palsy, muscular dystrophy, spinal cord injury, central nervous system disorders, or head injury. In addition, deformities resulting directly or indirectly from these pathologies are considered when designing a seating arrangement.

Fitting simulation

The first steps in the method consist of a thorough analysis and evaluation of the client's needs and a rigorous fitting on a versatile seating simulation chair. **Figure 1** shows the simulation chair. It allows a multitude of adjustments ranging from angles of tilt and recline to a variety of positions for the head rest, footrests, and armrests (13). Modular seating components or vacuum molding bags can easily be added (6). The simulation chair offers two major advantages. It is a versatile and flexible tool that guides the evaluation and determines the parameters of optimum seating. In addition, for minimal cost, it enables the seating specialists to observe and evaluate the pertinence and efficacy of the prescribed seating arrangement as well as the overall benefits.

After the evaluation using the simulation chair, the next step is to transfer the seating arrangement and parameters to the client's wheelchair. This is accomplished by taking measurements and readings directly from the simulation chair that is equipped with calibrated displacement gauges. Once measurements and readings are determined, a new seat and backrest are built with acrylonitrile butadene styrene (ABS) plastic plates 3/8-inch thick and installed at the proper position and tilt and inclination angles. The only limitations are the physical constraint of the wheelchair structure and the client's physical limitations. The ABS plates, designed to accommodate to any commercial wheelchair, will act as the interface between the wheelchair structure and the standardized seating components.

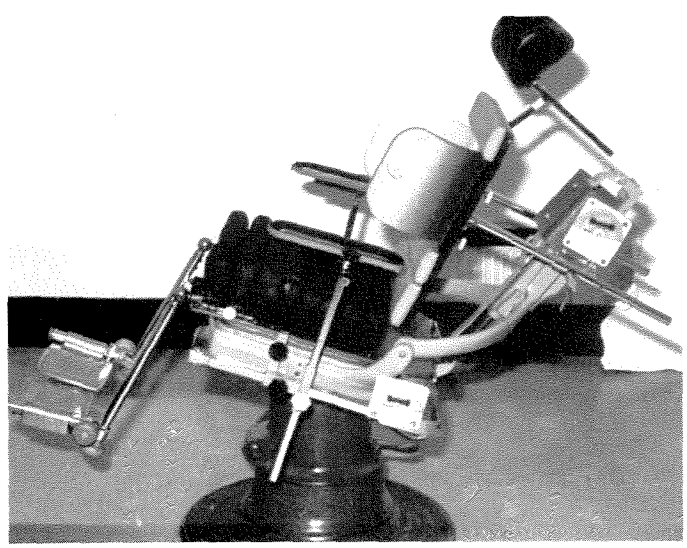

Figure 1.
Seating simulation chair.

Seating components

The next step takes a more empirical twist. Various pathologies have associated deformities that will dictate the type of seating components to be built on the anchored ABS plates. For example, an irregular seating posture requires full contour imitation and reconstruction through a molding procedure. By contrast, a relatively symmetrical seating posture generally requires standard modular seating components such as wedges, pelvic and thoracic supports, and foam contour accessories. In any case, the seating components (seat and backrest) are constructed on the ABS plates. One of the biggest challenges is to orient these plates in order to respect contractured limbs, tilt angle, requirements of table heights, and living quarters.

Designing components

The advent of CAD has added a new dimension to the techniques of seating protocol for wheelchairs. Solving the problem of wheelchair seating is the result of collaboration between l'IRM and l'Ecole Polytechnique de Montréal, the engineering school affiliated with the University of Montreal. User-friendly software has been adapted to create our system. CADKEY, the software (Microsystems Version 3.02), operates on an IBM-XT or AT, with a graphic display card and a co-processor (19). We chose this software because, at the time the project was initiated, CADKEY was the only true 3-D CAD software on the market that ran on a microcomputer. Evaluation showed that it was the most effective and appropriate software for our specific application. The CAD software has been adapted to permit the creation of a complete database.

With the help of dimensioned catalogue drawings provided by manufacturers, and direct measurements with a Vernier caliper or a type measure, over 150 wheelchair structures were entered into the database. All structures are drawn using the computer-aided design software and stored in separate files. The database includes most commercially available wheelchair models, including those manufactured by Everest & Jennings (as shown in **Figures 2 and 3**, Fortress Scientific (**Figure 4**) and Ortho-Fab (TARGA model in **Figure 5**), in addition to the series of standard seating components designed at the IRM to create user-specific seating. Each wheelchair is drawn to scale to include all its major structures. These include front and rear wheels, position and height of the vertical backrest tubes, and horizontal seat tubes. In addition, the crossbar position is indicated where the case applies. The system also permits reclining of the backrest tubes for recliner wheelchairs (**Figure 6**).

Standard seating components

For standard seating components, such as those shown in **Figure 7**, the database includes ABS plates, armrests, footrests, legrests, and a series of wedges and cushions. The system has been devised so that the user can select and display the wheelchair structure of choice on the computer screen. After selecting a particular wheelchair, the user can sequentially display and graphically manipulate any standard seating component in the database. To construct a seat and back, the plastic ABS plates can be manipulated to modify angles, height and depth, and tilt angle (**Figure 8**). This manipulation is guided by the fitting session on the simulation chair where parameters of optimum seating are determined. The

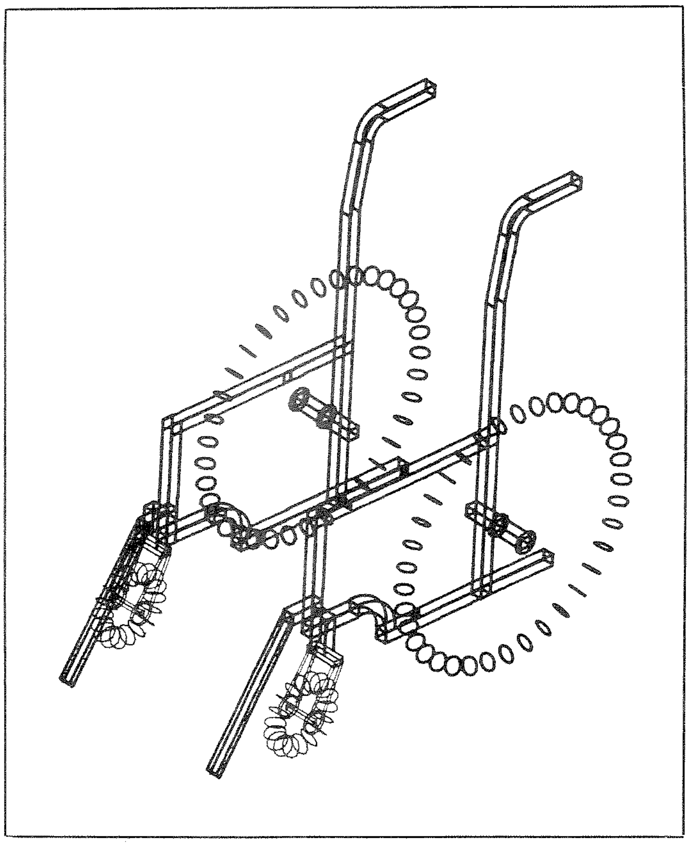

Figure 2.
Everest & Jennings manual model.

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same is done with any number of the standard seating components included in the database.

In addition, body segments and position can be simulated in order to verify body position and alignment of handrims, armrests, and footrests, with respect to the wheelchair base. It is important to note that new components can easily be added to the database simply by creating a new file and drawing them using the CAD software. All rehabilitation centers who use modular seating components could use this software, or any other 3-D software (such as AUTOCAD Release 9), and create their own database to use this application. After the desired seating arrangement is obtained, the CAD system and its easy final product dimensioning, creates a detailed technical drawing that is used during the construction phase, as shown in **Figure 9**. In summary, the software is designed to be used as a simulation tool for creating functional seating units. It is also a design tool that allows access through a database to dimensional information about commercial products and products developed at the IRM.

DISCUSSION

CAD versus manual reconstruction

In the past, because of various structural constraints, an ideal seating configuration and measured parameters obtained initially on the simulation chair were sometimes impossible to exactly reconstruct on a client's wheelchair. While trying to respect a client's specific requirements for function, there was a problem during the transfer of information from the simulation chair to the client's chair.

The following example will best explain the situation. Client X arrives at the seating clinic with a chair model Y of dimensions Z. After ideal seating is prescribed during the fitting session on the simulation chair, it is determined that for this particular configuration, a modular seat is required. The seat-to-backrest angle must be 95 degrees with a tilt angle of 10 degrees, and a seat-to-footrest height of 18 inches. The lap height must not exceed 30 inches to ensure clearance for most tables. Contractured legs limit posture at 90-degree knee

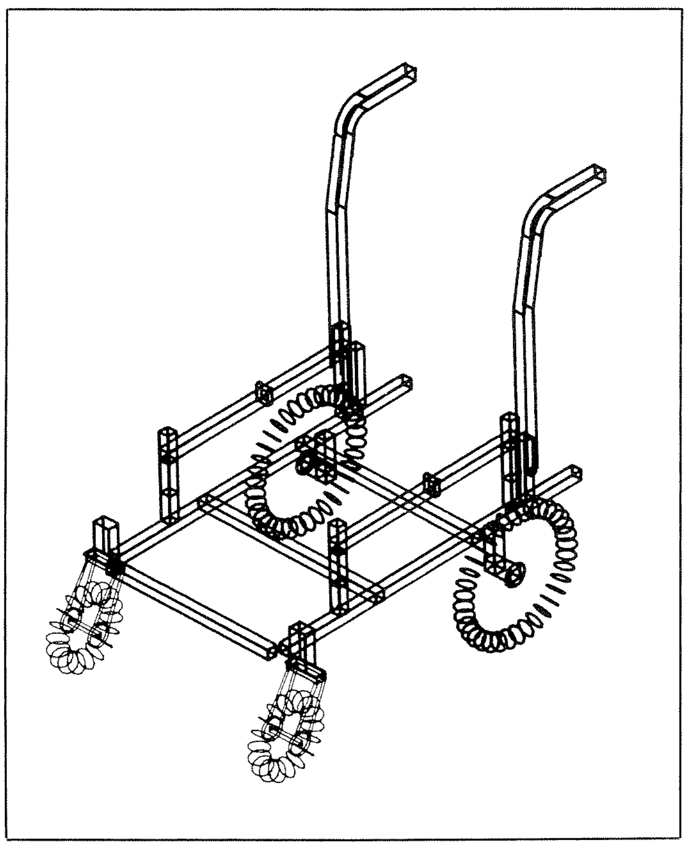

Figure 3.
Everest & Jennings Mooney base.

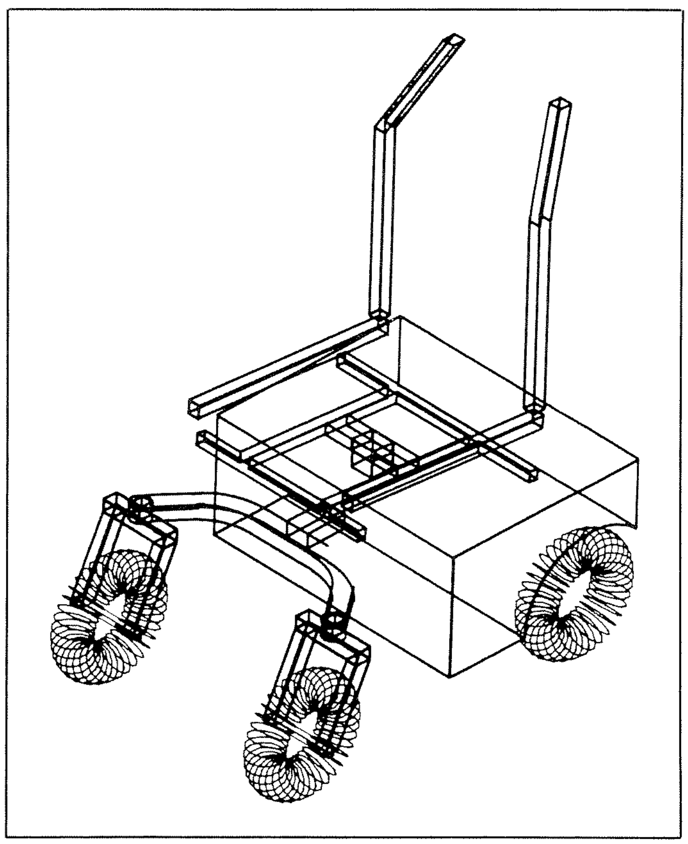

Figure 4.
FORTRESS model.

flexion. These requirements must be taken into consideration and reconstructed onto the client's wheelchair. It is important that footrests do not impede front wheel motion. Furthermore, in trying to achieve this by advancing a seating arrangement in a structure, the design should neither jeopardize the client's ability to mobilize by handrims and/or feet, nor compromise the stability of the arrangement.

CAD in single seating for different wheelchair designs

These considerations become even more serious when a single seating arrangement has to be designed for a client who has two wheelchairs. Structural constraints are now doubled. Appointments for proper fitting are longer and sometimes repeated. This situation is not uncommon, because most clients that have a motorized wheelchair often have a manual wheelchair for transportation purposes in a car or other vehicle. When the cost of a seating arrangement runs between $1,000 and $3,000, the advantage of not having to pay for a second one is obvious. The CAD system has a cost savings feature. It allows the user to verify and compare two wheelchair structure geometries and determine if the seating arrangement can be installed on either structure. Graphically representing the seating arrangement on both structures aids in determining the physical compatibility and functional aspect on both wheelchair structures. Once compatibility and functional requirements are determined, hardware interfacing is ensured by connectors that have been designed at the IRM. Appropriate connector positions are determined by the CAD system and indicated on the detailed technical drawing.

EVALUATION

Computer-aided drafting and design has been operational in the IRM seating clinics since September, 1988. It is now being used during weekly seating

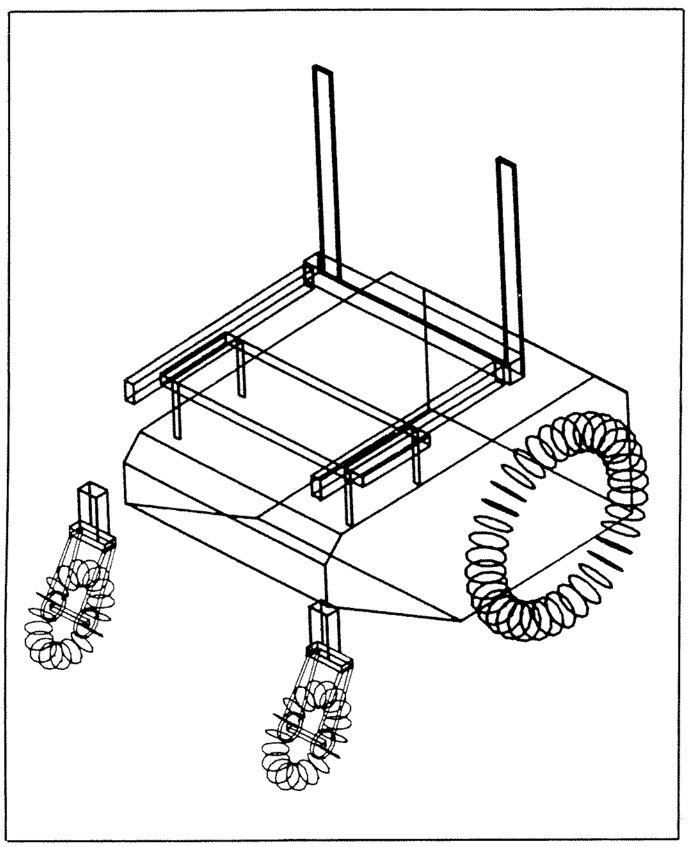

Figure 5.
TARGA model of Ortho-Fab Company.

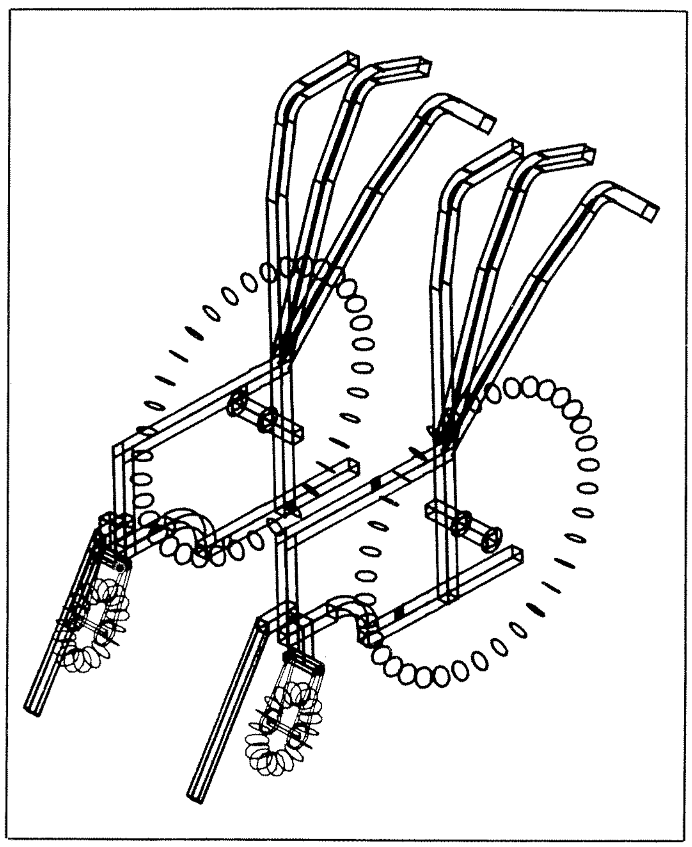

Figure 6.
Example of flexibility of backrest tube inclination.

clinics to produce plans for fabricating client's seating arrangements. The evaluation of the system has just begun: preliminary results are promising. Seating orthotists who use the system to create the technical drawing are optimistic and encouraged by the results and by the idea of using this system.

A complete protocol has been established to evaluate the advantages of using the CADKEY system in our seating clinic. We will compare the times required to produce two seating arrangements with approximately the same degree of fabrication difficulty. One will be built by the trial and error method and the other one will be using the technical drawing produced by the CAD method. Clinic time and number of visits will be monitored. Time required to become familiar with the software and time required to create the technical drawing is taken into consideration. Any change made to the software will be noted.

Since clients do not participate in any stage which involves the CAD system, their appreciation of the end product will be evaluated one week following delivery and also four months after delivery. This evaluation, in the form of a questionnaire, will include topics such as comfort, time spent in seating arrangement (presently and ideally), and expected results versus actual results. The final stage of the evaluation will be a cost analysis to determine if the introduction of CAD contributes to efficient and financially worthwhile service delivery.

CONCLUSION

Preliminary results demonstrate that with the advent of CAD, most criteria governing a specific functional seating arrangement are more easily met. Direct on-screen visualization of structural as well as

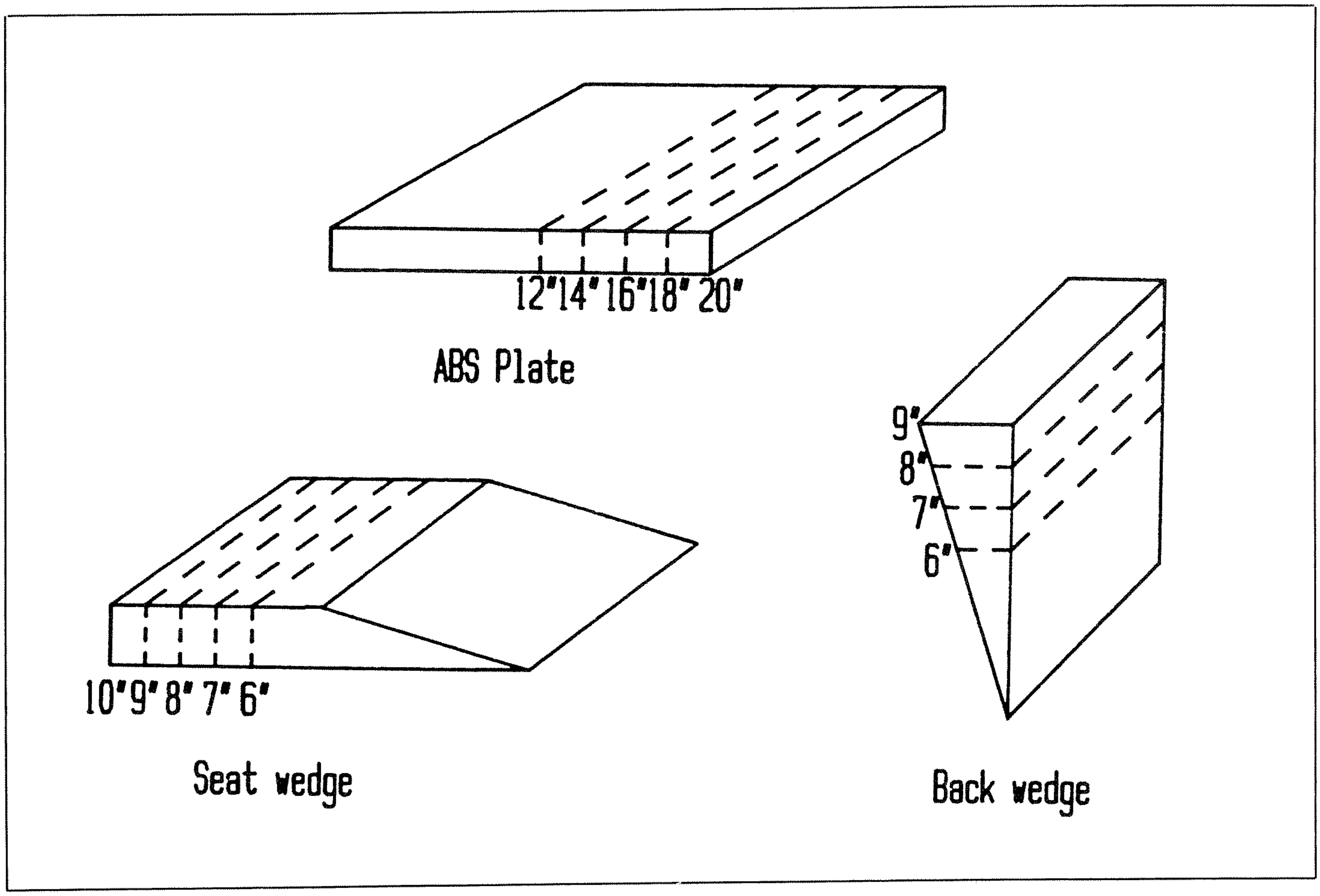

Figure 7.
Examples of standardized seating components.

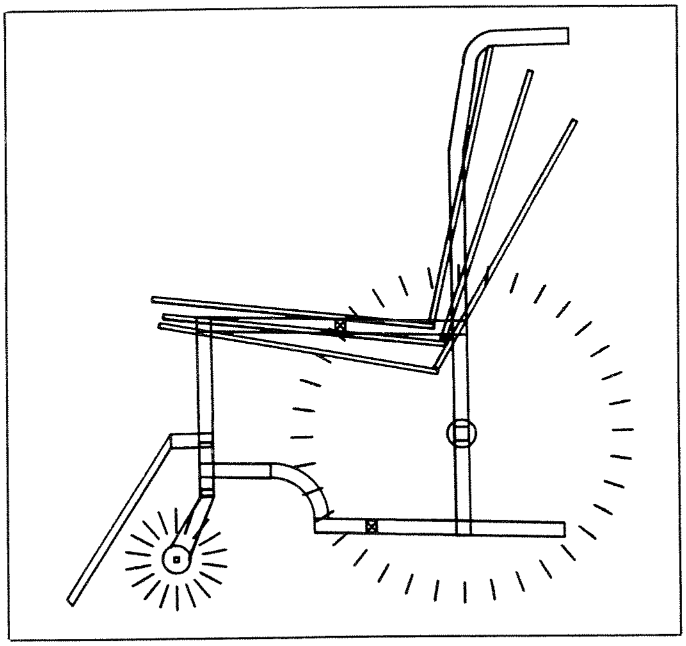

Figure 8.
Possible seat and back arrangements.

physical constraints is possible. Thus, they can be taken into consideration while creating the final technical drawing that is used during the construction phase. The CAD approach to solve various problems has proven to be an effective tool to complement and simplify the seating method designed at the IRM. This preconstruction visualization and design allows seating specialists to simulate a client's seating unit on the wheelchair to determine a functional position before fabrication. This should produce economy of time and money, and, more importantly, it should provide clients with a more effective seating orthosis and a better service.

The CADKEY system is presently in use at the facility, and preliminary results are promising. Furthermore, this idea can be used by other rehabilitation centers who wish to make their own database to create a simulation tool that is suited for their specific seating needs. Finally, the volume of client technical files and dossiers is reduced, and access for continued consultations and modifications is made easy. Overall, the client as well as the seating specialists should benefit.

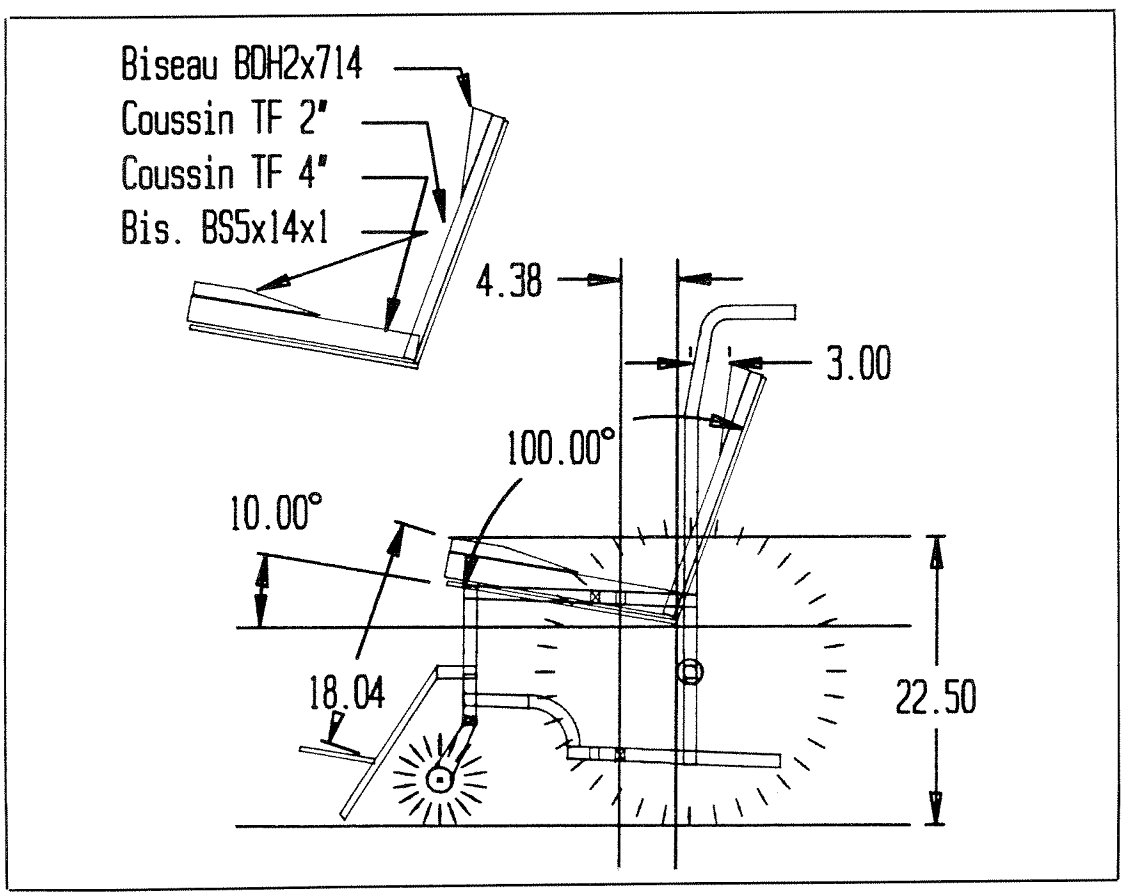

Figure 9.
Dimensioned seating arrangement ready for construction phase.

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