3. Organisational procedures and production technologies that recognise the unique nature of refurbishment work.

The project is subdivided into 3 main tasks:

Task 1 Development of a decision support system to ascertain refurbishment demand and ballpark costs.
Task 2 Development of a decision support system for refurbishment design and production planning and control.
Task 3 Development of a decision support system underlying a commercial framework for refurbishment.

This paper addresses the implementation issues of the DSS for refurbishment design in task 2.

2. PROBLEM DEFINITION

In task 2 of the research project two essential parameters for housing refurbishment design are identified: user requirements on the one hand, and the existing building condition on the other. The objective of this part of the project is to develop a rationalised method which, based on these two parameters, leads to a number of possible design solutions.

Housing refurbishment design starts with a detailed description of the constraints that follow from the existing situation. These consist of geometrical constraints (e.g. the position of the bearing walls), material constraints (e.g. damaged finishes), functional constraints (e.g. required floor areas), and economical constraints (the intended investment).

The design decision process covers two major stages. In the first stage the investment level and the new function of the building are determined. These decisions are normally taken by real estate investors or housing corporations. In the second stage variant layout solutions are evaluated and the choices for specific material usage are made. These are decisions taken by the new owner and/or user of the building apartment, often represented by a housing corporation.

Ideally, the decision process should not be a linear process, but one that can be re-executed under different conditions to support the evaluation of different strategies and solutions. For discussion with the client about the refurbishment design, a graphical presentation of the new apartment interior is very helpful. On-line product information is needed to look for building products that meet the client's preferences. Essential is to find the right level of product description, namely one that can be understood by the client.

To support a cyclic refurbishment design process, a tool is needed that can help the owner/user, i.e. the housing corporation (advisor), in taking the right decisions by interactively evaluating different strategies and solutions. The proposed system is a Knowledge Based System (KBS) that includes knowledge about architectural design variants, cost consequences, and building product applications.

A methodology that suits this purpose is Case Based Reasoning (CBR). The basic principle of CBR is that it supports the reuse of existing design knowledge. This is achieved by storing design problems, design solutions and design outcome for specific design cases, as is done in, e.g., [Maher and de Silva Garza, 1996]. If one is confronted with a new design problem, the case base is searched for similar design problems using some search criteria. After finding a case the existing design solution and outcome will be presented. The next step is to adapt the retrieved design to the actual situation and then to learn about the consequences of the adaptations with regard to specific performances (e.g. economical performance).

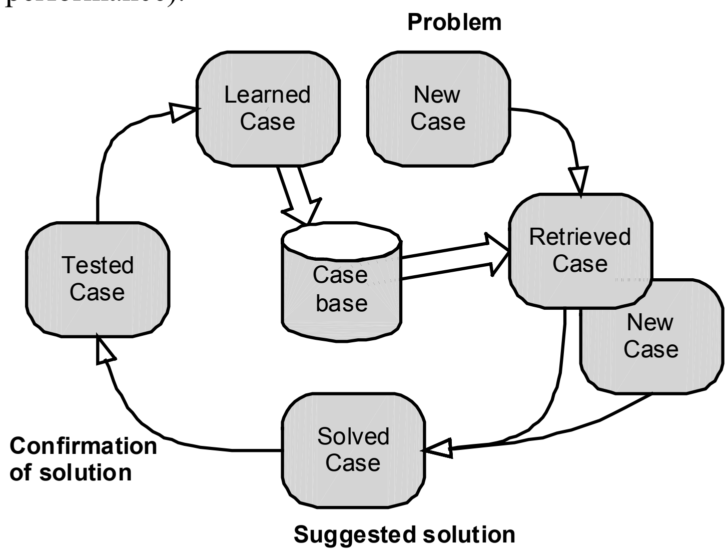

Figure 1. Case Based Reasoning, after Aamodt and Plaza, 1994.

In apartment buildings, general layout principles can be recognised for a large percentage of all apartments. Examples of studies on generalisation of architectural layouts can be found in [Steadman, 1983], [De Chiara & Callender, 1980], [van Leusen, 1994], and [Sherwood, 1979]. Consequently, it is possible to compile a database of typical housing layouts that, when filled with a sufficient number of cases, will offer a fair chance of finding acceptable resemblance to the refurbishment situation at hand. CBR is a useful methodology for structured access to such a database of existing design cases. In this approach, matching cases will be searched for on the basis of geometrical, material, functional, and economical constraints.

3. DESIGNED SOLUTION

3.1 Process model

The decision support, in this project, for the refurbishment design process uses a database of typical existing housing layouts in a CBR method of selecting the closest match from this database to the actual refurbishment case at hand. For each of the existing layouts, a number of designs showing typical variants of refurbished layouts have been added to the database. The design support procedure continues with assisting in the selection of the preferred layout from these variants. On the basis of this preferred layout, the systems and components in the design are evaluated and products to be used in the refurbishment project are selected.

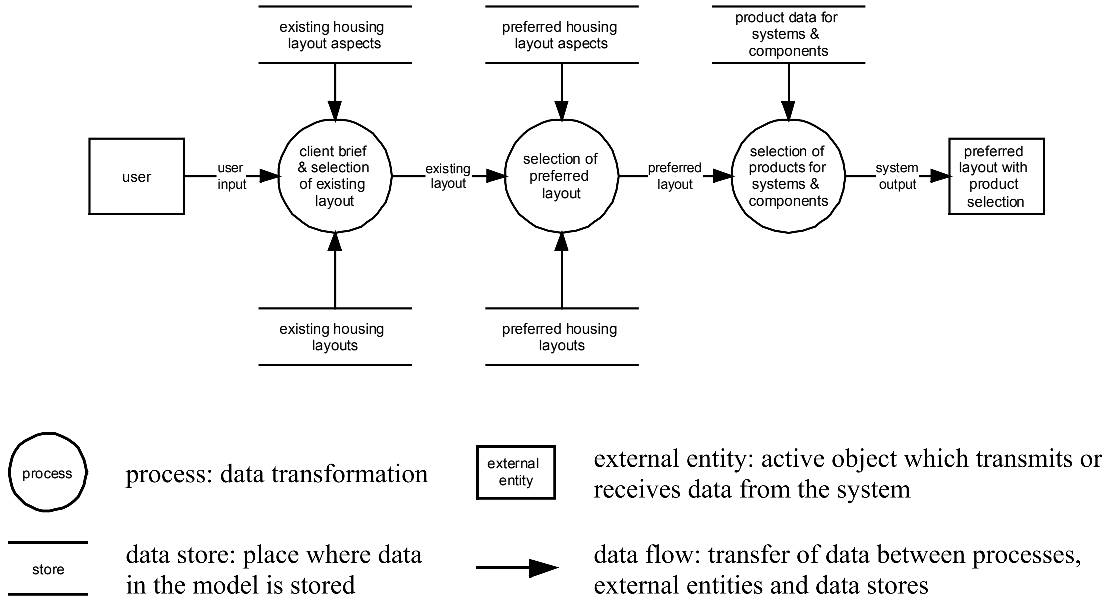

Figure 2. Decision Support System Process Model

Process step 1: Client Brief and selection of Existing Layout

The process starts by selection of a typical existing housing layout from the database that sufficiently matches the layout of the actual refurbishment situation at hand. This selection process is performed using one of the following methods:

1. The user browses through the list of typical existing housing layouts while viewing the floor plan. Initially, the case base will include approximately 12 such existing housing layouts.
2. The system first sorts the existing housing layouts on the basis of a set of characteristics. Each existing layout in the case base is classified by a predefined set of performance aspects, which can be compared to the values that the user enters for these aspects to describe the actual refurbishment situation. Examples of these aspects are the number and size of the various rooms in the apartment. All existing layouts are evaluated and sorted according to their score in matching the user's data. The user can subsequently browse through the sorted layouts. In section 4.1 this procedure is further elaborated.

Process step 2: Selection of Preferred Refurbished Layout

Using the previously selected typical existing housing layout as a point of departure, a set of variant refurbished layouts will be evaluated to meet the requirements for refurbishment determined by the user. This is again done either by browsing through the available refurbished layouts or by specifying the same kind of performance aspects that were used to select the existing layout. An additional mandatory requirement to be specified by the user is the refurbishment level (minor, average, major). Obviously, all variant layouts are classified by the same predefined set of performance aspects and by the level of refurbishment related to the existing layout that each of them is based on.

The variant refurbished layouts are presented in an order determined by the score of matching their characteristics with the user requirements. Evaluating the variant layouts, viewing their characteristics and plans, the user selects the preferred refurbished layout. Since each of the variants includes a specification of systems and components, selecting the preferred layout automatically selects the number and kind of systems and components that are involved in the refurbishment. These systems and components are then further specified in step 3 of the process.

Process step 3: Fill in Systems and Components in Preferred Layout
The systems and components in the floor plan of the selected preferred layout are decomposed in a number of subcomponents. For each of these components, product information from suppliers is included in the system's database. The decision support process involves determining the user's preference of products to be used for each of the subcomponents in the refurbishment. This task of selecting products is supported by allowing browsing and querying the product database. All the product data of the various systems and components are classified by a predefined set of descriptors in a format that is specific for each subcomponent.

3.2 Data model

The data model underlying the above described decision support process involves both graphical and alpha-numerical data. For process steps 1 and 2, the graphical data includes the floor plans of both existing and refurbished layouts. For each existing layout, there is a number of refurbished layouts. Both existing and preferred layouts are graphically represented by way of a DWF file (Autodesk's Drawing Web Format).

All layouts are classified using a set of performance aspects that are indicated by way of values of an alpha-numerical data type. Figure 3 shows the data model for the relationship between existing and refurbished layouts, the performance aspects, the aspect values, and the relationships of aspects and values with the existing and preferred layouts.

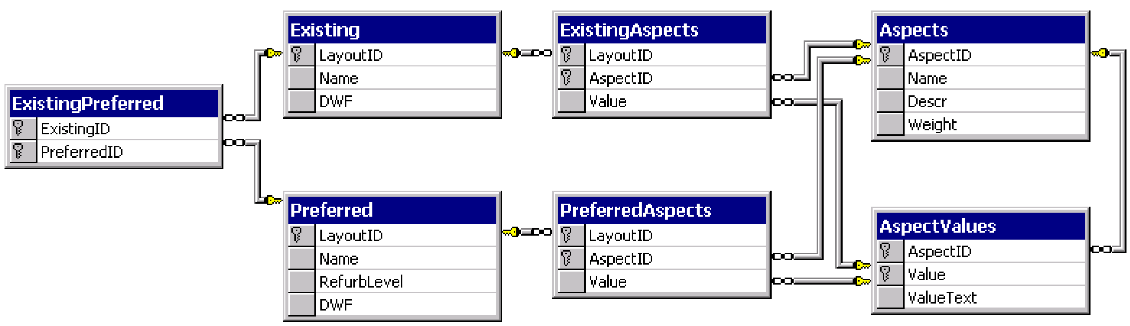

Figure 3. Data model for performance aspects of existing and preferred layouts.

For step 3 of the process, the data model includes the specification per variant refurbished layout of the systems and components that are involved in the particular refurbishment. The systems and components are decomposed into subcomponents, for which product data is included in the database. The specification of systems and components for each of the refurbished layouts is implemented by way of labels that are added to the graphical representation of the layout. Thus, the graphical representation plays an active role in the data model.

The decomposition of the systems and components is restricted to a single level of decomposition. For example, the Wall component is decomposed into the subcomponents Structure and Finish. These decompositions are determined in a fixed model that is shown in the appendix of this paper. This model is specific for refurbishment design decisions and has been determined by the industrial partners in the research project, based on daily practice in the refurbishment discipline.

Each of the subcomponents is represented by a table of product data, of which the structure varies per subcomponent. This means that all WallStructures are described using the same parameters, but that WallFinishes use other parameters. The database therefore contains table definitions for each of the types of subcomponents that exist in the decompositions of the systems and components. An example of the table definition of the subcomponent WallStructure is shown in figure 4.

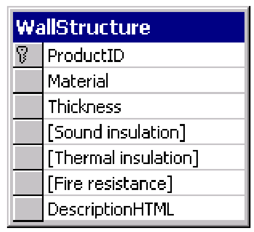

Figure 4. Data definition for the subcomponent WallStructure.

The product data is described using a number of fields that are considered to be the search criteria for the process of selecting the appropriate products. Additional information is provided in HTML format and related to the database by a field containing the filename of the particular HTML page ('DescriptionHTML'). These HTML formatted product pages can have a layout that is characteristic for the supplier of the products and may include text, graphics, and multimedia.

4. SYSTEM DESIGN AND IMPLEMENTATION ISSUES

The system is designed as an Internet based client-server application. The major advantages of this approach are the central maintenance of the database and server-side software, and the minimal software and resource requirements at the client-side. This allows the system to be used in a multi-user environment, with low-end computers at the client-side that are not dependent of special software. However, it does make the system dependent of the availability of Internet, but this is generally not considered a problem.

The server-side part of the system is based on Microsoft NT Server technology, using Internet Information Server (IIS) and SQL server. The implementation of the system is described below in two sections. The first section describes the tool that constitutes the actual decision support system, indicated as the User tool. The second section describes a tool that is developed for maintenance support of the system.

4.1 User tool

The decision support system is accessed from the Internet, using standard browsing software and an additional plug-in for viewing the graphical Autodesk DWF format. The web interface for steps 1 and 2 in the process as described above allows specification of performance aspects for the selection of existing and preferred layouts respectively. Figure 5 shows the interface for querying and browsing the database of existing layouts.

First, the performance aspects are set by the user to represent the actual refurbishment situation. The values specified for these aspects are used to evaluate and sort the existing layouts available in the case base. This evaluation is done using a cardinal decision method, more specifically, the weighted objectives method [Roozenburg and Eekels, 1995, p. 306]. The total score of performance P of a particular alternative A_i is determined as follows:

$$P(A_i) = \sum_{j=1}^{m} \lambda_j s_{ij}$$

For every alternative layout A_i, each aspect value is compared to the requested performance. This can lead to an exact match, resulting in a score s_{ij} equal to zero, an over-performance scoring +1 to +4, or an under-performance scoring -1 to -4. The score s_{ij} of each of the aspects is multiplied by a weighting factor λ_j indicating the relative importance of each aspect. The total score, finally, is determined by the sum of the weighted scores of all aspects.

The weights of the aspects in the total performance score are fixed and determined by experts participating in the research project. However, the user of the system has the option to indicate that certain aspects should not be taken into account in this evaluation procedure, as is done, for example, for the 'size of master bedroom' aspect in the left window of figure 5.

Using the interface on the right in figure 5, the sorted set of layouts can be browsed through, while viewing the floor plans and the specification details. This part of the interface also displays how the currently selected layout performs in relation with the criteria set by the user. As an example, the figure shows a layout that has an under-performance of -2 for the aspect 'size of bathroom'.

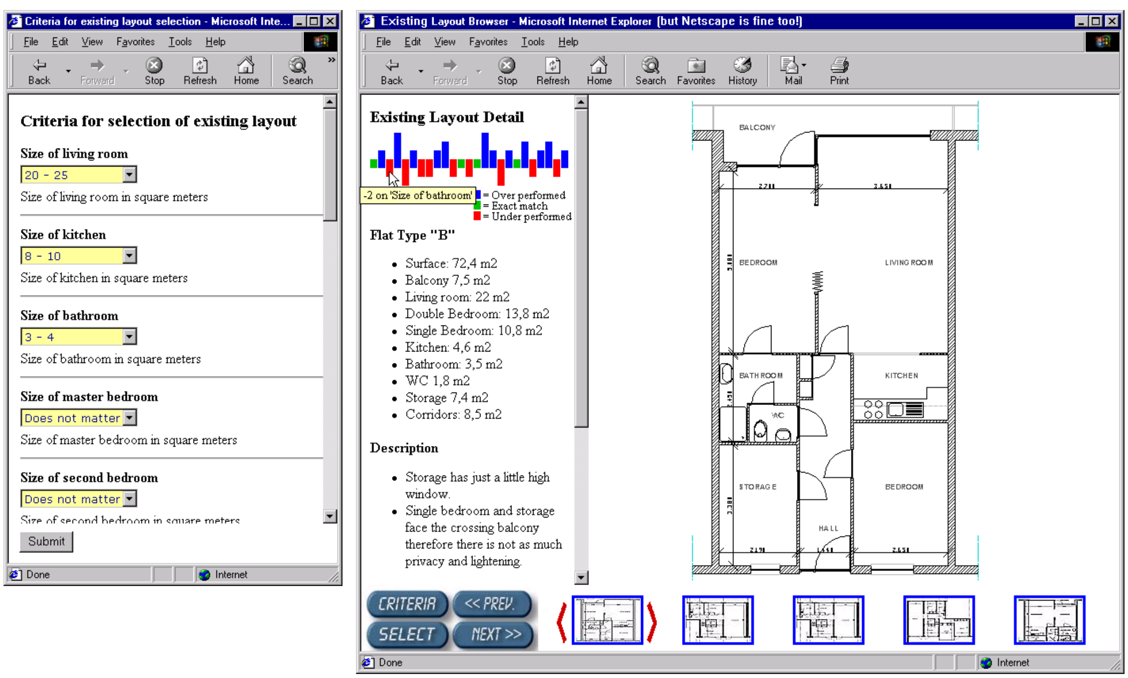

Figure 5. Querying and browsing the case base of typical existing housing layouts.

The selection of the preferred refurbished layout uses the same kind of interface as the one shown above, be it that this time the performance aspects of the requested refurbishment are indicated. An additional aspect is requested from the user to indicate the level of refurbishment that is planned for the building. Since refurbished layouts are always based on an existing layout, the previously selected existing layout also narrows the search space for refurbished layouts that fulfil the user's requirements.

Once the refurbished layouts are sorted accordingly to the total score of their aspects as compared to the user's requirements, the user can browse through the plans, again viewing the details of each layout. The user now selects the preferred refurbishment layout.

With the selected preferred refurbishment layout, the user continues to specify the products to be used in the refurbishment for systems and components. The interface for this task is shown in figure 6. This interface shows the layout on the left, which includes labels to indicate the systems and components that are involved in the particular refurbishment. After selection of one of the systems or components, its decomposition in subcomponents is shown in the centre of the window. Each of the subcomponents can be selected in order to specify the preferred product to be used in the refurbishment project. This selection is done from the product database that can be filtered using a number of descriptors. These are displayed on the right, in the example they are 'Material', 'Thickness', 'Acoustic insulation', 'Thermal insulation', and 'Fire resistance'. The product data can be queried using a Query By Example (QBE) method. The 'Material' field in the example is filtered on the value 'Bricks'.

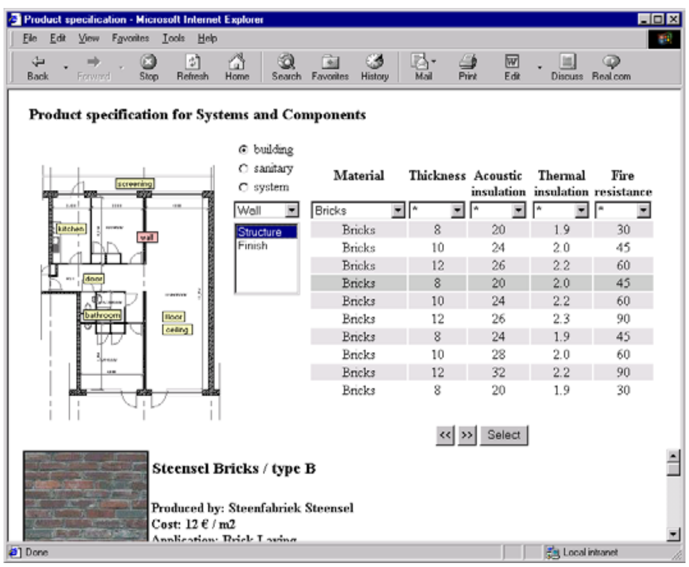

Figure 6. Specification of products for systems and components.

The interface for this task is built up dynamically on the basis of the user's selection in the graphical representation of the layout. Since the table definition of the product data varies per subcomponent, the interface must be updated whenever the user changes the selection in the layout or in the decomposition list. Using the arrow in the lower right of the window, the user can navigate through the records, while viewing the detailed product description for the active record in the bottom of the screen.

4.2 Maintenance tool

Maintenance of the system is necessary on two fronts. The product data for systems and components must obviously be entered into the systems database and subsequently kept up-to-date. Since this is information that originates from product suppliers, it is most likely that the data will be offered in bulk using a digital medium. As a consequence, maintenance of this part of the system will be possible using standard import facilities of the database server.

More complicated is the maintenance of the part of the system that contains the case base with graphical layouts, their interrelationships, and their relationships with the performance aspects and the systems and components. Here, the original information is not so likely to be available in digital format. Most likely it will be information that is generated for the specific purpose of filling the case base. Therefore, a maintenance tool is developed that allows a number of tasks to be performed:

1. importing CAD drawings of layouts (AutoCAD DWG format);
2. adding clickable labels for systems and components;
3. exporting the drawing to the drawing web format (DWF);
4. uploading the drawing to the server;
5. indicating relationships between existing and refurbished layouts.

This tool can be used client-side, since it does not require direct access to the server's database. The actual transfer of data to the server is done using upload forms in an Internet browser. The relationships of refurbished layouts with the systems and components are implemented through the labels that are added to the DWF formatted layout.

5. DISCUSSION & CONCLUSIONS

Refurbishment design requires a decision support tool that takes advantage of the specific circumstances, i.e. a very constrained design task to be performed in close cooperation with the user. The information needed to construct such a decision support system for, e.g., a housing corporation is not available in most cases. The required information consists in the first place of a database of floor plans of the real estate that is owned by the particular housing corporation. In case of a refurbishment project the consulted architect should be asked to provide refurbishment alternatives with a global indication of the costs. This information should be stored for future use together with the original floor plan. Other required information comes from building product suppliers. They should provide the product information in a prescribed format.

For housing corporations it will require some extra effort to create a portfolio of their real estate. However, the benefits of reusing this information and offering detailed decision support to customers are very clear. To attract suppliers to provide product information in a specific format, there must be an economic pay off. The economic pay off will stem from the fact that the refurbishment market is a growing market and that product choices increasingly depend on the suppliers' presence in a refurbishment decision support system.

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APPENDIX: DECOMPOSITION OF SYSTEMS AND COMPONENTS

Building components

Wall
- Structure
- Finish

Ceiling
- Structure
- Finish

Floor
- Finish

Staircase
- Stair

Door
- Door

Window
- Window

Screening
- Shutter
- Rolling shutter
- Fly screen

Sanitary components

Bathroom fittings
- Bath
- Basin
- WC
- Bidet
- Shower
- Mixer

Bathroom special equipment
- Towel rail
- Handholds
- Soap dish
- Toilet paper bearing
- WC-seat
- Mirror
- Folding seat

Kitchen fittings
- Basin
- Cooker
- Units
- Mixers

Systems

Heating system

- Radiator
- Fresh air radiator
- Floor heating
- Piping
- District heating substation
- Gas fired boiler
- District heating pipeline
- Gas pipeline

Ventilation system

- Exhaust air valve
- Fresh air inlet
- Fresh air radiator
- Supply air grille
- Exhaust air ducting
- Supply air ducting
- Exhaust air fan
- Supply air unit
- Combined supply and exhaust air unit

Plumbing system

- Tap for WC
- Tap for dishwasher
- Tap for washing machine
- Cold water piping
- Hot water piping
- Sanitary sewer
- Water meter
- Hot water generation
- Cold water connection module
- Sanitary sewer connection module
- Storm water connection module

Electrical system

- Outlet socket
- Outlet socket for luminaire
- Switch box
- Wiring
- Main switch board
- Metering unit
- Connection to utility network

Telecommunication system

- Outlet socket for TV antenna
- Outlet socket for radio antenna
- Outlet socket for phone, modem, ISDN, Intercom
- Wiring
- Main distribution board
- Connection to utility network

Security system

- Detection device (Sensor)
- Wiring
- Security alarm control unit
- Alarm bell/siren
- Fire alarm control unit
- Connection to security company
- Connection to fire brigade

Auxiliary system

- Room air conditioner
- Waste separation cupboard