SIMULATION OF CLEANING
AS A USEFUL TOOL IN PLANNING OF BUILDINGS

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ABSTRACT

Simulation of cleaning is a new area in building simulations. To make rational cleaning is it important to know how difficult it is to clean rooms. I define a Cleaning Index (CI) as the cleaning area divided by the floor area. High CI is difficult to clean. A simulation program CIX calculates the CI based on an object-oriented 3D model of a room in the VRML-format. The program will find all horizontal surfaces, where the dust can settle. The result is presented in graphical form or in tables. Use of the method is shown for a classroom and two offices. The simulation of cleaning is very useful in planning, design, operation and maintenance of the building. Cleaning costs is much more important than the energy costs. The 3D model in VRML can also be used for internal heat- and moisture balance and for indoor air quality evaluations.

INTRODUCTION

Computer simulations have been used for many years to calculate energy consumption and thermal conditions. Architects can present the interior of a planned building to clients using visual modelling as in figure 2. The models can also be used in engineering - in this case to find out how difficult it is to clean a room. Most building simulations is made with empty rooms without thinking on the users influence but in the case of cleaning is it necessary to know the furniture in the room.

We use much time for calculating the energy costs of buildings, but the cost of office cleaning is much more important as it is 25 to 50% of the building management costs. The energy cost is 10% to 20%. The cleaning sector has traditionally been a low-tech area with many people employed, but we all need cleaning. Good cleaning is important for a good indoor air quality and a better work environment. The computer has changed office work - one of the new areas in change is cleaning.

The cost of cleaning depends on the required cleaning quality and on the difficulty in cleaning the room. To make rational cleaning, it is best to have large free spaces without obstacles. In practice a room will always have obstacles such as furniture - chairs, tables and shelves. Most offices are filled with furniture that has been selected based on design, price and usefulness. The price is usually a decisive factor. The wrong selection of furniture can make cleaning difficult and increase the cleaning costs.

Figure 1. Photo of a classroom

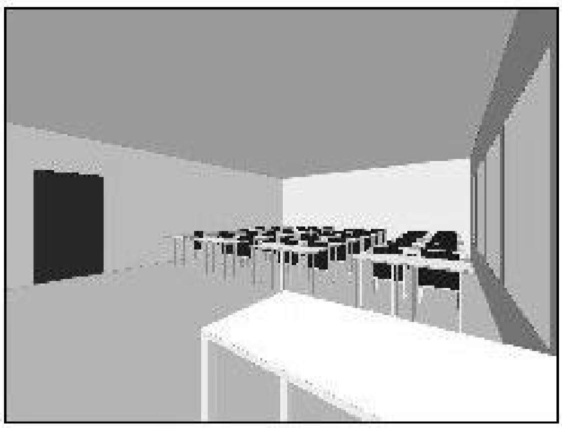

Figure 2. 3D-model of the same room

The traditional method of evaluating cleaning cost in an existing building for instance the class room in figure 1 is to make an inspection and from experience classify the room as ***easy, average*** or ***difficult*** to clean. Considering this classification the cleaning company can estimate cleaning time and cost.

This approach is not very practical, if we plan a new office and want to compare different layouts or furniture types. We need a method that can be used for comparison in the planning and purchase phase. The method I use is based on the ideas described in Nielsen 1995 and Nielsen 1996.

THE CLEANING INDEX

I use a classification based on cleaning area as both cleaning time and cost must depend on that factor**.** The cleaning area is the horizontal surface that has to be cleaned.

The cleaning index (CI) is defined as the cleaning area (CA) divided by the floor area (FA).

For a free space defined as a room without walls and furniture the cleaning area (CA) is equal to the floor area (FA). The CI of a free space is 1. All rooms with obstacles will have a CI > 1.

Rooms have walls and they make the cleaning more difficult - particular in the corners. The following formula is used to calculate the cleaning area (CA) from the floor area (FA) and the wall perimeter (P) at the floor level in an empty room.

Room cleaning area: $CA = FA + P * 0.2$ (m^2)

The factor 0.2 on the perimeter is an estimate of the extra time used and is defined as an extra cleaning area of 0.2 m's width along the perimeter. The factor can be found in time studies of cleaning. From the cleaning area we can calculate the CI for rooms and compare different room sizes and layouts in the planning phase.

All horizontal areas in the room such as windowsills, doorframes and surfaces on furniture will increase the cleaning area and the CI. I do not include vertical areas in my calculation of cleaning areas, as these surfaces normally do not have to be cleaned as often. Horizontal areas above the floor are normally cleaned by different methods than the floor is. We can classify these areas depending of the cleaning method for instance - glass cleaning, textile cleaning and cleaning of hard surfaces. For a typical room we need the geometrical areas divided into **floor cleaning areas** and **furniture cleaning areas.** The furniture cleaning area can be divided in two types - hard surfaces and textile surfaces.

Definitions of CI indexes (cleaning area divided by room area) for an room:

Empty-CI is the CI for the room without furniture

Room-CI is the CI for the floor of the room with furniture

Furniture-CI is the CI for horizontal surfaces above the floor

Total-CI is the sum of the Furniture-CI and the Room-CI

3D MODELLING

Five to ten years ago, a real 3D drawing program was very expensive and needed to be executed on workstations or mainframe computers. Today the situation has changed completely - you can buy a 3D drawing program for 30 to 125 US$ off the shelf. In these cheap programs you can get most of the functionality from the older large systems. These programs are typically used to make architectural layout of rooms with furniture and fixtures.

The program can show the result as 2D plans or 3D drawings with colours and textures on the surfaces. The program package includes libraries of predefined 2D or 3D objects as boxes, tables, chests, chairs, doors, windows and so on. It is therefore easy to construct a room or a building in 3D. It is also possible to customise objects for the model. It can be a new model of furniture to get at more realistic 3D model.

VIRTUAL REALITY AND WALK THROUGH

During the last years a new 3D-file format has emerged - the Virtual Reality Modelling Language (VRML). This language started as a method for distributing 3D geometric information via the Internet. It defines a “world” consisting of blocks, cylinders, etc. from which the user can build rooms and buildings. The VRML describes a 3D world you can walk into and explore by “walking around” by different programs, “browsers”, which are available on almost all machine platforms.

This gives the possibility of constructing games with rooms and static objects in VRML version 1.0, where you can “walk through” and see the world from different angles. In VRML version 2.0 and VRML 97 objects can be moved by the user and taken to another room. This gives a virtual reality, where you can change your world on the screen and see the results.

The VRML format is easier to parse than other often used 3D formats and it is not too complicated to use. Figure 3 is an example of the definitions for a room. The first section defines the coordinates (x,z,y) for the eight corners. The second section defines the material properties: colours and transparency of the surfaces. In this case all surfaces have the same colour. The third section defines the six surfaces in the room. Each surface is defined by a number of corners ending with –1. The numbers 0 to 7 are the first to the last coordinate in the list in the first section.

```
#VRML V1.0 ascii
Separator { #Polyhedron
DEF COORD0 Coordinate3 {
   point [
    0.0000 2.0000 -4.0000,
    0.0000 2.0000 0.0000,
    -3.0000 2.0000 0.0000,
    -3.0000 2.0000 -4.0000,
    0.0000 0.0000 -4.0000,
    0.0000 0.0000 0.0000,
    -3.0000 0.0000 0.0000,
    -3.0000 0.0000 -4.0000
   ]
} #Coordinate3
Material {
ambientColor     0.2118 0.1696 0.1196
diffuseColor     0.8471 0.6784 0.4784
transparency     0.0000
} #Material
IndexedFaceSet {
   coordIndex [
    0, 1, 2, 3,-1,
    0, 3, 7, 4,-1,
    1, 0, 4, 5,-1,
    2, 1, 5, 6,-1,
    3, 2, 6, 7,-1,
    7, 6, 5, 4,-1,
   ]
} #IndexedFaceSet
} #Polyhedron
Separator { #Polyhedron
```

Figure 3. Example of VRML-file for a room of 4 x 3 x 2 m. The first section defines coordinates for the eight corner points. The second section defines the colours and third section the six surfaces in the room.

At Narvik Institute of Technology we have found the VRML language to be a very useful tool for 3D visualisation of simple geometry and as a basis for technical calculations Nielsen (1995, 1996, 1998) and Nielsen and Bang (1996).

SIMULATION WITH THE CIX-PROGRAM

The calculation of the cleaning index is based on simple calculation and geometric rules. The drawing of the room and furniture is done in a cheap 3D CAD-program used for virtual reality as described in Nielsen and Bang 1996. The program includes an object-oriented 3D model of rooms and libraries of furniture. The CIX-program is written in Visual Basic and reads the information from the CAD-program in VRML-format. From this information is calculated the different areas in the room and cleaning indexes as described in an earlier section.

The user can select pieces of furniture and position them in the room and see the change in the CI. The output is a drawing of the office with furniture as figure 6 and calculated cleaning area (CA) and cleaning indexes (CI).

This type of calculation can also be used on existing rooms to find out where we will get cleaning problems and then give advice - for instance moving some pieces of furniture. The CIX-program can be very helpful for many problems in facilities management. We can use the object-oriented model to produce lists of all the furniture and for instance the computers in the building. We can get an inventory, that can very useful if we want to reorganise the activity in the building. In that case we have to move people, furniture and computers. The program can show, if we can reuse the furniture and if we can make cleaning easier by a new layout.

COMPARISON OF OFFICE ROOMS

The first case is a layout of a new office. I use a typical single person office with a door in the short end and a window at the other end as seen in figure 4. There are two cases with different areas R8 with 8 m^2 and R12 with 12 m^2 both with a desk, two chairs and two cabinets.

Figure 4. View of R8 office

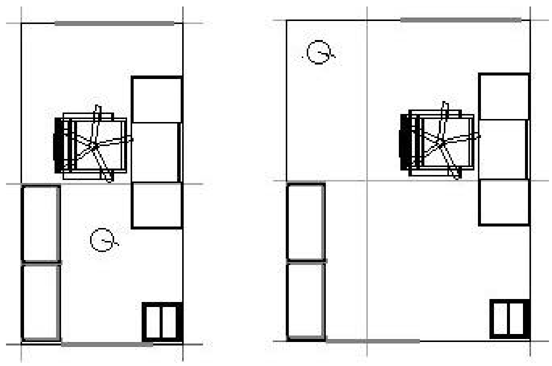

Figure 5. Plan drawing of the two offices R8 and R12 (from left to right). The small circle with a radius is the observer in the room.

Figure 5 shows a plan drawing from the CAD-program of the two offices as seen in the program. Figure 6 is a copy of the screen you will see with a plan to the left and a view to right seen from the observer (marked as circle with radius in the left part).

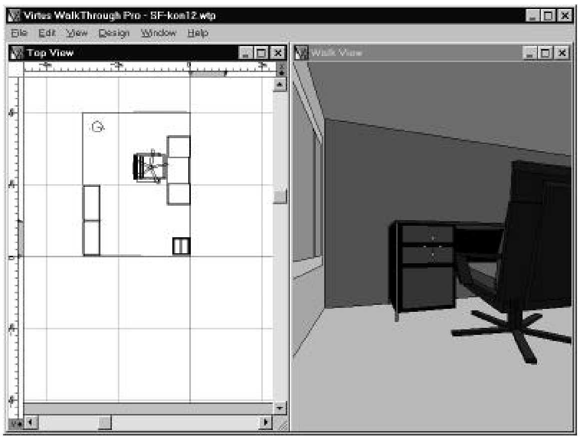

Figure 6. Screen from CAD-program

The two office layouts in figure 5 are used to calculate the cleaning index (CI) with the CIX-program. In table 1 is the calculated CI-value. The Total-CI is for instance for R8 is 1.82. The cleaning area is therefore 1.82 times the floor area. The Empty-CI is decreasing for a larger room as expected. There is less area along the wall. The Room-CI, the Furniture-CI and the Total-CI decrease from R8 to R12 as we have the same furniture in both rooms. The furniture will have less influence in a larger room.

Table 1. Calculated CI-values for the rooms

	R8	R12
Empty-CI	1.3	1.23
Room-CI	1.48	1.35
Furniture-CI	0.33	0.22
Total-CI	1.82	1.58

An example of the use of areas in analysing office space in Japan is found in Naka 1996. He has looked on the area pr office worker and defined:

- the furniture factor is equal to the furniture area divided by the floor area.
- the circulation factor is equal to the circulation area divided by the floor area.

The circulation factor is around 46% and the furniture factor around 29%. The furniture factor is not the same as the furniture-CI as I can have cleaning areas in different heights. But if we compare we can see that R8 has 33% furniture cleaning area or around the same as in Japan. A larger office that will be more normal in Scandinavia R12 has a lower furniture factor of 22%.

The result from the CIX-program is a drawing showing where it is difficult to clean the floor. Figure 7 and 8 are the results for R8 and R12. It is seen that there is much more free space (medium grey) that is easy to clean in the large office.

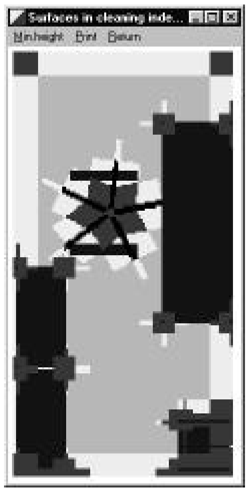

Figure 7. Plots from the CIX program of room R8. Dark grey areas are either impossible to clean (red) or below furniture (blue). Medium gray (green) areas as in the central part of the floor are easy to clean. Leight grey (yellow) areas as along the walls are difficult to clean.

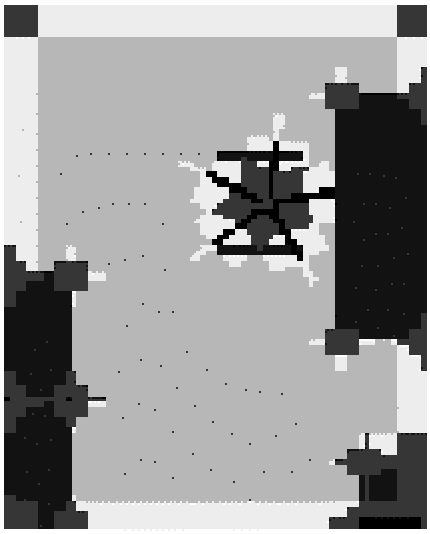

Figure 8. Plot from the CIX program of room R12. Colours as figure 6.

In table 2 we have the numerical values. The Free Floor is the area that is easy to clean. The difficult area is along walls and furniture. The impossible areas can not be cleaned or is very difficult. The furniture area is below furniture, if there is an open space less than h cm between the floor and the underside of the furniture. An h value of 75 cm will include areas under tables. These areas can in most cases be cleaned without too many problems. If h is less than 30 cm then it is more difficult. The effect of the value of the height can be seen in table 2.

Table 2. Results from the CIX-program for the two rooms in two cases - if no cleaning is done under furniture that has an opening between the floor and lower level of furniture of less than h. The Free Floor is easy to clean. The Difficult area is along walls and around furniture. The impossible area and the Furniture area can not be cleaned.

		R8	R12
No cleaning h<30 cm	Free Floor	45%	58%
	Difficult	24%	20%
	Furniture	19%	12%
	Impossible	12%	10%
No cleaning h<75 cm	Free Floor	40%	56%
	Difficult	20%	16%
	Furniture	28%	18%
	Impossible	12%	10%

CLASSROOM

The second case is a classroom from Narvik Institute of Technology taken from the report of Jensen and Pedersen 1999. Photos of the room is seen in figure 1 and 11 and the built 3D model in figure 2. The calculations of the cleaning are based on a simplified model of 12.5 m^2 with furniture for nine students as seen in figure 9.

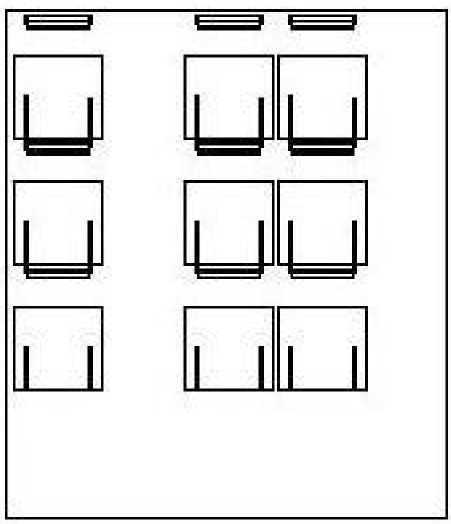

Figure 9. Plan of the classroom.

The results show that the legs on the tables make the cleaning difficult (large dark grey areas in figure 10). This is also seen on the photo in figure 11. The Empty-CI was 1.23, the Room-CI 1.5, the Furniture-CI was 0.32 and the Total-CI was 1.82. The floor area is similar to the R12 office but the Total-CI is higher. The plot shows that it is important to change the legs to make cleaning more practical and easier done.

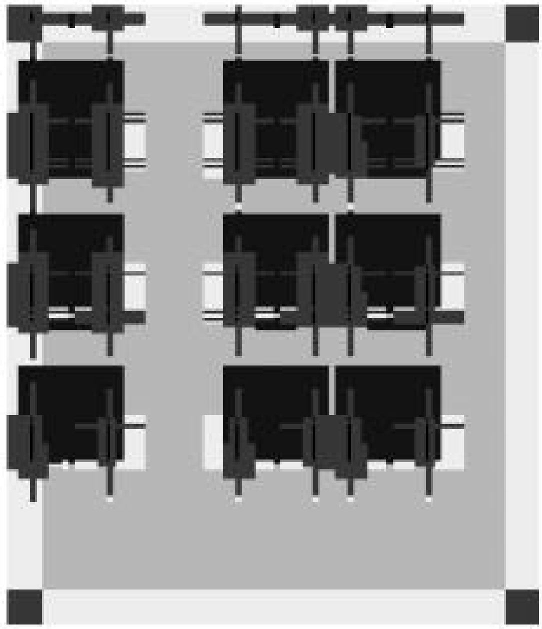

Figure 10. Plot from the CIX program of the classroom with h<75 cm. Colours as figure 6.

Figure 11. Photo of the tables and chairs in the classroom.

ACCESSIBILITY FOR ROOMS

A special version of the CIX-program can be used to find if it is possible to move a cleaning equipment or a wheel chair around in the room.

This can give a very good information for planning for wheel chair users or for using mobile cleaning equipment. It is easy to see the areas that can be reached and areas that are inaccessible. In figure 12 and table 4 is the result for a wheel chair of 120-cm times 90-cm in office R8. In this case is the medium grey area divided in two parts by the chair. It will be impossible to come to the window in the room if the chair can not be moved. We have similar problems if we want to move large furniture into the room.

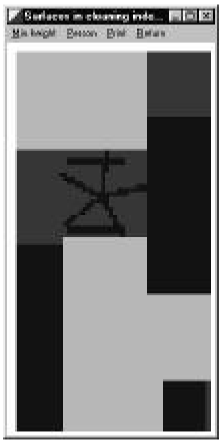

Figure 12. Plots from the CIX program for accessibility for a wheel chair (size 120 cm times 90 cm) of room R8 – extra dark grey areas are below furniture and dark gray areas are impossible to reach. Only medium grey areas can be reached.

The Furniture percent in table 4 gives the area that can not be reached because it is occupied by furniture. The Impossible percent gives the area that can not be reached, as there is not space for the wheel chair. The Free Floor is the area, where a wheel chair can move.

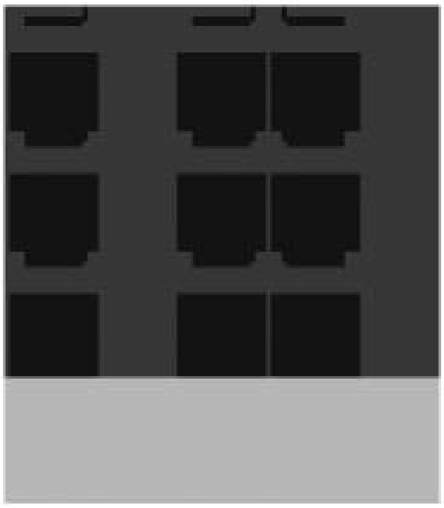

Figure 13. Areas where cleaning machines can be used (medium grey 24%) in the classroom.

In schools it is interesting to use cleaning machines. If the size were 120 cm times 80 cm the result would be as in figure 13. Most of the room could not be cleaned by machine. Using the program I have found that if the size was 120 cm times 60 cm will it be possible to clean the gangway between the rows of tables and chairs. This information of where cleaning machines can be used is important to select the best equipment.

Table 4. Result of accessibility for a wheel chair (size 120 cm times 90 cm) for the two offices.

	Free Floor	Furniture	Impossible
R8	48 %	32 %	20 %
R12	70 %	21 %	9 %

PRACTICAL USE OF SIMULATION OF CLEANING

If we complain about cleaning it is very easy to say: It is the cleaner that does not do the job. In many cases, there are areas in the room, that can not be reached by normal cleaning and the user can have lots of papers all over the desk as in figure 14. The graphical presentation in the 3D model and the result from the CIX program makes it easier to present and understand the cleaning problems for both the cleaner and the user. For the office in figure 14 it will be a good idea to take away the paper and the PC's on the table at least once pr month to clean the table surface.

Figure 14. Table with papers and PC's in an office

OTHER USES OF THE VRML-MODEL

Using a standard 3D modelling system is much faster than trying to write it from start. The combination of 3D modelling and technical calculations will be a very interesting research area in the future because we can use the geometry to many different things. The architects will use it for preliminary layout of the building and show the interior with realistic colours and textures to give a very good presentation for clients. The engineer must be able to use the 3D model as a base for technical calculations. Many solutions should be calculated in the design phase to find the best solution. Later many parameters as for instance the geometry has been fixed and it is much more difficult to change things. We must be able to use simple 3D model before we come to the actual detailed construction. This is discussed more in Nielsen and Bang 1996.

I have made a program that can find all surfaces in a 3D VRML room model made with a cheap 3D program. All surfaces are sorted by size, colour and orientation. This is a basis for models in the following areas.

Heat Balance. From the 3D-room model we can calculate surface areas of different types. Areas of windows and doors can be found. A method is to use different colours for different constructions in roof, floor and walls and then calculate the areas of each colour. It is possible to combine the 3D models with a simplified program for energy consumption, so that it is possible to get a good estimate of the energy consumption based on an outline of the building. Today is many energy consumption calculations first done after a detailed 3D model has been made and then it is very difficult to make changes in the design. We can also find the volume of furniture in the room. This is interesting for calculations of heat capacity.

Moisture balance in rooms. We have many measurements of moisture absorption and desorption for different types of materials but this is seldom combined into a full moisture balance for a real room. In some cases we have measured the moisture content in the air and ventilation rate in rooms but this is not used in a calculation to see if the moisture balance fit with the measurements. With a 3D model of the room it is easy to define the material on each surface and then let the computer find the total areas of the different materials. In the room model can we define colours of the surfaces, but we can not give direct information of the material. That is because the computer programs are made for visualisation and not for engineering purposes. We use an indirect method by using different textures or colour on the surface and find the areas of these. Each colour is a type of material. In the 3D model of the room is it very easy to change some materials in the layout and from a 3D view we can see if the room looks correct. That can prevent mistakes in the calculation of surface areas and later in the moisture balance. Use of 3D models for moisture balance calculations is described more detailed in Nielsen 1999.

Indoor air quality. To find the best materials for use in rooms we test small pieces in test chambers to measure the emission of gasses from the material over time. Then we have the same problem as with moisture, that this is seldom combined with the information of materials and areas in a real room. A 3D model is again a very good help. The same methods that are used for moisture balance calculations as in Nielsen 1999 can be used.

Light in rooms. In rooms we are interested in day lighting and electric lighting. This has until now been handled by rather complicated computer problem, but some algorithms for light are included in most 3D visualisation programs to get a more realistic view. These algorithms are not calculating physical correct, so we can not find the lux values. But you can find programs that can make a correct calculation based on a 3D model.

Maintenance and life-cycle cost. A 3D model is also helpful in the building maintenance. It is for instance rather easy to find out wall or floor areas from the model. This is important for pricing of renovation with for instance painting of the walls. Most computer maintenance system is based on text based information that has to be put into the computer. In the 3D model is should be much easier to find different types of surface types. The 3D model can be used for planning of changes in the use of rooms. This could be reorganisation of the use in part of the building including new furniture or reuse of old furniture It is easier to see the consequences and take the best decision after a "walk trough" in the model and calculations of the cost. The 3D model can be very useful in life-cycle cost calculations as many of the cost depend on areas or volumes that is easily found in the 3D model. The problem is that people in maintenance of buildings see a 3D model as only an extra cost and more work to keep it updated. The benefit will first come if the basis has been made with the 3D-model.

CONCLUSIONS

I describe a systematic method, which can be used for classification of cleaning easiness for rooms with or without furniture. The method can be used both for planning of new rooms and for evaluation of existing rooms. The method can be summarised as follows:

1. The CI for a room defines how difficult a room is to clean. The lowest possible CI is 1.0 but most office rooms with furniture will have a Total-CI from 1.5 to 2.

2. The calculation methods have been implemented in a data program CIX, where the user can see a drawing of the room and select furniture from a database. The furniture can then be moved around in the room to find the best layout. The result can be seen in 3D virtual reality. Based on this information the CI for the room and plots of easy and difficult cleaning areas are produced.

3. The CIX-program can be used for selection of type, product and layout of furniture. It is

easy to compare different solutions to find the one with the lowest cleaning area.

4. It is possible to evaluate accessibility for instance for wheel chairs or cleaning equipment in the planning of new rooms or to find problems in existing room.

It is explained that the methods for finding areas can be used also for heat- and moisture balances for room and for evaluation of indoor air quality problems. I believe that 3D models will be a very useful tool in building maintenance and life cycle cost calculations.

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More examples of the use of virtual reality and VRML can be found on my web-page address: http:\www.hin.no\~an\

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