Summary of the research project

A computer-aided decision-making tool for the rapid capture and assessment of data in the early phases of building within existing built contexts using an IFC-based CMS

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1. Aim of the research project

1.1. The problem

For all building measures undertaken on existing buildings, the kind and condition of the existing building has a significant impact on the costs. The greater the damage to a structure, the higher the proportion of repair costs with respect to the overall revitalisation costs. Given its impact on the overall costs, the ability to determine the cost of repair measures during the initial phase of a project would therefore provide an important basis for assessing the financial viability of a revitalisation project.

At the beginning of a project, however, it is difficult to accurately assess the repair costs as a factor of the overall costs, as necessary data concerning the existing building is often unavailable, imprecise or based on assumptions. A comprehensive survey and damages assessment in the initial phase is not viable, both in terms of cost and time. Nevertheless, the HOAI, the German architectural services catalogue, lists this as a service to be undertaken by architects during the preliminary assessment phase [Depenbrock02].

The difficulties described can lead to errors in the initial cost estimate and potentially to risks not being identified and therefore not planned for. This results in costs exceeding budgets and time delays further down the line and, ultimately, to a poor investment.

1.2. The approach

As part of the research project "Digital building documentation as a basis for decision-making in the planning of existing buildings", which is a collaboration between partners from research and practice, a concept for the rapid computer-aided capture of data in the early phases of building within existing built contexts and a corresponding cost estimation (and risk assessment) module has been developed and realised in prototypical form. The research partners are the Chair for Computer Science in Architecture at the Bauhaus-University Weimar and the CAAD department at the TU Munich. The practice partners are the AWO Thüringen from the field of property management, RKS from the field of construction operation and project management and Kubit and Syslab as software developers.

The aim of the concept is to identify all the possible risks of a project at an early planning stage, and to assess these as a basis for making informed project decisions.

Using this concept, the condition of the building is recorded and assessed and the cost of necessary construction measures – in particular repair measures – is determined. As neither the initial condition nor the target condition is fully known at such an early stage of a revitalisation project, all the possible sets of construction measures should be considered. For this a stochastic technique has been chosen, the so-called Monte-Carlo-Simulation, to calculate the probability of the expected costs (see fig. 1).
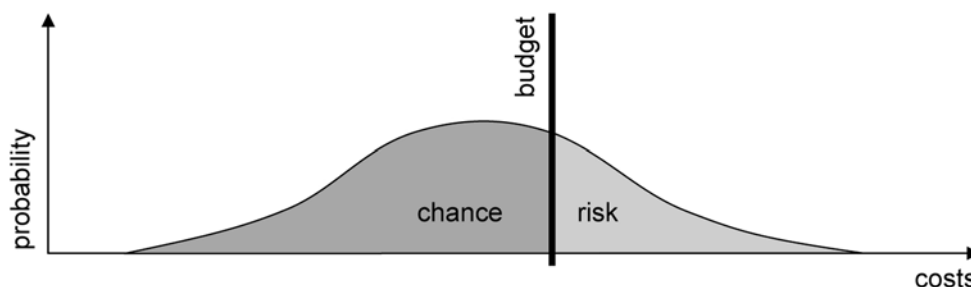
Fig. 1: **Schematic diagram showing the probability of the expected costs after taking all possible works involved for a revitalisation project into consideration**

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By comparing the probability distribution for the expected costs with a predetermined budget for the revitalisation project, the risk potential of project financing can be assessed, providing a transparent and comprehensible basis for the client to make appropriate decisions.

2.   Research approach

The focus of the project was to develop a practical approach for undertaking an early cost and risk assessment and to implement software prototypes that are usable on site. The project work was carried out into four main work packages:

- Cost-risk-analysis

- Data modelling / building information model

- Sketch-based data capture

- Content Management System

The data required to make this assessment should be recorded on site using computer-aided methods and stored in a Building Information Model (BIM). This initial survey needs to be undertaken quickly and effectively, using a sketch-like approach and associated interpretation of the data. Data that needs recording includes the basic spatial and structural structure of the building, the condition of the building elements and any visible damage. This data enables the user to determine which repair measures are necessary, and from this to estimate the costs involved.
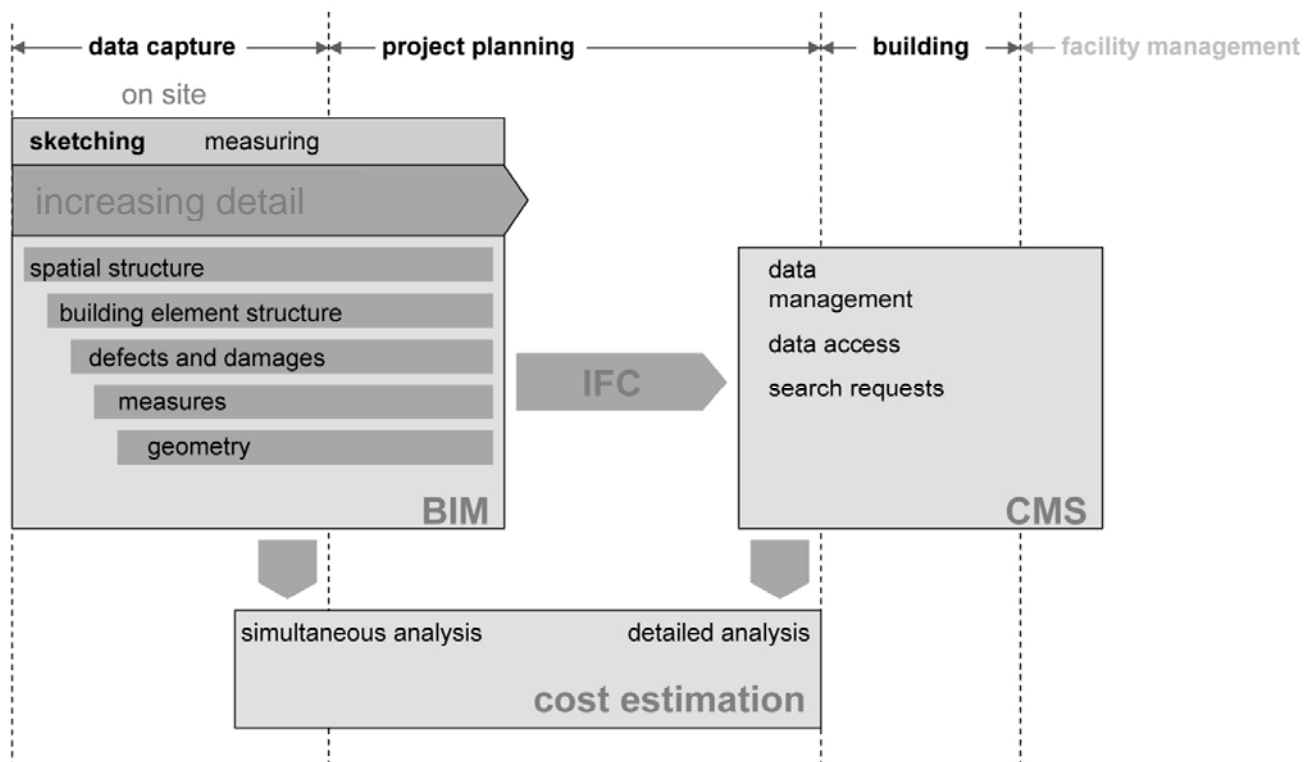

Fig. 2:   Schematic diagram of the system concept and its sub-modules

After the initial survey and initial cost estimate, the recorded data can then be made available for the later planning stages. To facilitate this, the BIM has been developed in an IFC-compatible form allowing the export of IFC-files. These are then imported into a web-based content-management system (CMS), so that it can be made available to all participants in the planning process. The CMS allows one to query the BIM-model, or parts thereof, according

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to specific architectural or technical criteria and supports the allocation of different access rights. Similarly, the CMS should be able to run queries across several BIM-models. Figure 2 shows a schematic diagram of the system concept and its sub-modules.

3.   Summary of the results

3.1.   Cost-risk analysis

In the preparation, planning and execution of renovation projects, various kinds of costs arise which are classified into cost groups in the German DIN Norm 276 (Kosten im Hochbau – Building construction costs). The costs groups 100 – 700 are further subdivided into three sub-levels respectively, e.g. the cost group 331, load-bearing external walls is a sub-level of cost group 300 (building structure).

For the purposes of a preliminary cost estimate in the initial phase of a renovation project, cost groups 300 "Building – Building Structure" and 400 "Building – Technical Installations" are most relevant as these costs make up the greater proportion of the overall costs and can only be determined relatively imprecisely. It is, however, still possible to influence these costs quite significantly over the course of the planning. These play the most important role in financial cost calculations, followed by the land purchase costs and planning fees, and the financing costs which in turn are a factor of the sum of all the other costs.

In our system concept, the capture of the building structure of the BIM is structured according to the cost groups defined in [DIN 276]. The user assesses the condition of the building during the survey (damage-free, good, bad, disastrous) and notes any visible defects. The data capture and assessment of damages can be undertaken in stages of successively increasing detail, beginning with the overall assessment of the building and proceeding on to the assessment of element groups (e.g. all external walls) to the detailed assessment of individual construction elements. For the purposes of determining costs, the levels of detail can be grouped into three stages as follows:

Stage 1	Overall evaluation of the entire structure and cost estimation
	based on reference costs according to the:
	• Measurement of the external dimensions and number of storeys
	• Data regarding type, function and condition
	• Data regarding the region, time of construction, and ancillary building costs
Stage 2	Supplementation of the existing values with, for example:
	• Precise details regarding gross and usable floor area
	• More exact data regarding the type, condition and size of individual building element groups
	• Supplementary/replacement measures
	• Repair of selected damages
Stage 3	Supplementation of the existing values with, for example:
	• Precise details of individual building elements
	• Precise details of quantities and measurements
	• Determination of specific building measures
	• Repair of further damages

Table 1: Excerpt of cost estimation stages with increasing level of detail of available building data

It is possible to switch between different levels of detail as required; one need not adhere to a particular approach for the entire building. For example, it is possible to record information regarding a detailed part of the building structure (Stage 3) in one part of the building while

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for another part, one has only recorded the external dimensions and general condition (Stage 1).

By assessing the condition and noting particular damages (for example water ingress and the area affected), the user is able to assign the appropriate measures required to remedy the problem or upgrade the condition of the building. As it is sometimes impossible to know the true extent of damages or defects at the time of the initial survey, a list of possible relevant building measures can be stored in the system together with the probability of their occurrence (EW) in groups of "building works". For example, in some circumstances one cannot tell if damage is confined to the surface or also affects the structure beneath. Accordingly:

- Works 1: Repair surface, cost=X, EW=80%
- Works 2: Replace surface material and construction, cost=Y, EW=20%

To assist in the selection of appropriate measures, the user is presented with a catalogue of predefined measures. These are obtained via a link to existing building cost databases that list descriptions of building works. The probability of their occurrence is either defined by the user or suggested by the system. The suggestion function is based on previously entered probability data and depends on the existence of values entered previously or in earlier projects.

Through the allocation of different building measures, a series of different possible revitalization alternatives can be produced along with their corresponding cost estimates. The probability of the different variants can be determined with the help of Monte-Carlo Simulation and represented in the form of a graph. This stochastic approach involves undertaking a large number of hypothetical random experiments. For the purposes of our cost estimation, individual building measures in each group of measures are selected according to their probability of occurrence and the cost of the respective variant is calculated. After a large number of simulated project alternatives have been conducted, a diagram of the expected costs and their probability is generated (figure 3).
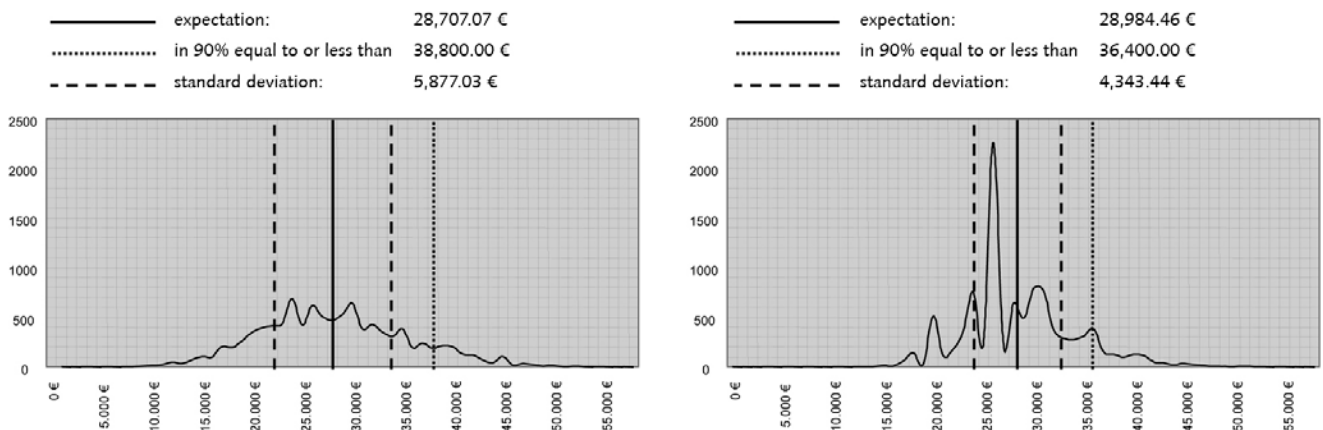
Fig. 3: **Example results of a Monte-Carlo Simulation based on data provided up to cost estimate level 2 (left) and level 3 (right)**

The diagram provides the client with a reliable indication of the expected costs as a basis for future decisions. Aspects of high risk and uncertainties can be derived from the graph and accordingly taken into consideration during the project coordination. In addition to the assessment of all possible variants, it should also be possible to consider only certain variants in order to determine their effect on the overall costs.

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3.2.   Sketch-based initial survey

At the beginning of a renovation and conversion project, the level of investment and therefore the volume of the resulting contracts is difficult to assess. Accordingly, the initial survey of the existing building as a basis for assessing costs and risks needs to reflect this: it should be both effective and straightforward to undertake.

For this reason a stylus-based input device was chosen for the software concept which can be used for sketching, handwriting and gesture recognition. Examples of relevant hardware are Tablet PCs or UMPCs. These are both sufficiently powerful and easy to handle on site.

The recorded data is stored in a proprietary BIM structure. The necessary data structure for the model is a product of the requirements of the later cost and risk assessment:

- Overall spatial structure
- Overall structure of the construction elements
- Damages and condition of construction elements
- Building measures
- Building geometry

The system provides three different input modes which differ according to the input and interaction technology used as well as the interpretation and representation of the data to be recorded:

- Sketch Mode,
- Capture Mode,
- Survey Mode.

3.2.1.   Sketch Mode

This mode enables the user to enter supplementary informal data in the form of a freehand sketch. As these are not interpreted by the system, they are not subject to the same input formalities as the interpretable sketch, whose interpretation algorithm necessitates a particular procedural approach.

The resulting freehand sketches are therefore not interpretable by the system but can serve as a further representation of the individual elements in the spatial or construction element models.

3.2.2.   Capture Mode

This mode provides the standard input functionality for the recording of the spatial arrangement of the building, the structure of its construction elements and the recording of damages. Tools for the creation of lines of walls and boundaries of rooms, for openings and denoting damages are provided. The user makes a freehand sketch of the plan of a floor using the stylus. The system interprets the sketch (digital ink model) and converts this internally, connecting perpendicular lines, into the interpreted sketch model. The system employs the functionality provided by the Microsoft Windows XP Tablet PC Edition SDK [Microsoft08].

The user sees the representation as a sketch so that the original imprecise input remains visible rather than creating the impression of a precisely measured model.

In addition to the interpretation of the sketch, the organisational structure of spaces and construction elements is also created. Lines are interpreted as wall segments or virtual boundaries of spaces; if the lines enclose an area, a room is created and so on. Openings and damages can be inserted in the form of symbols attached to the sketch and appear simultaneously as elements of the construction element model.

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3.2.3. Survey Mode

The two-dimensional vector model created from the interpreted sketch is transformed into a 3D surface model and presented to the user. For each of the lines drawn in the sketch, two parallel planar surfaces are created which represent the surface of the building element for each respective segment of wall. Geometric constraints can be applied in this mode (parallel, orthogonal, symmetrical, etc.) and measurements can be added. The 3D-model is successively adjusted to fit the dimensions measured using computational adjustment. This functionality is based on previous research undertaken at the chair and is documented in detail in [Thurow04], [SFB524_05a] and [SFB524_05b].
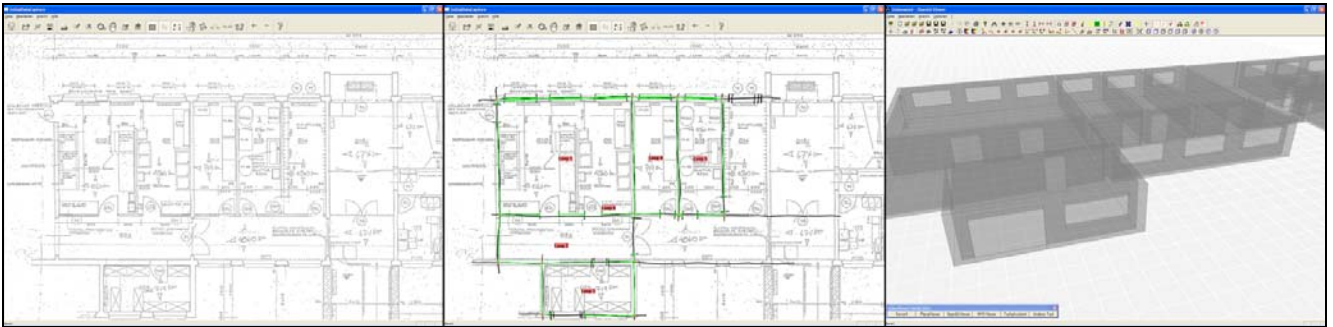

Fig. 4: **Software prototype InitialDataCapture – Use of existing data (scan) as an underlay, creation and interpretation of freehand lines, and derivation of 3D geometry (from left to right)**

3.3. Content Management System

Content management systems distinguish themselves by the fact that any content is organized, e.g. in the form of text, photo or CAD documents within a web-based system. On this occasion, interfaces are used for the import and export. The different contents can be administered according to individual rules. An advantage of many content management systems is the fact that they provide in-built functionality for user access rights and roles. An administrator can define which groups of participants may access which data at particular stages as well as who may edit and insert new data.
For our research project, we used the open source CMS Plone[1] and adapted it to the project requirements.
The system concept is designed so that the building information model from the initial data capture passes to the CMS for further use in the planning process. For this the IFC data exchange format is used, which allows data to be exported as a plain text file for import into the CMS. Nevertheless, searching for certain elements within the IFC model is problematic. A pure text string search in relatively large volumes of data is too ineffective. Instead, an IFC Parser was developed which organizes the content of an IFC file into tables within the CMS database, making it possible to conduct database queries substantially more efficiently on many projects simultaneously.

3.4. Prototypical realisation

Based on the system concept, a prototypical implementation of the system was developed as a proof-of-concept for different aspects of the system. This was implemented as separate modules using different development environments, sometimes based on existing software systems. The individual modules are networked with one another via interfaces to facilitate

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[1] http://plone.org/

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the system concept workflow from data capture at different levels of detail to cost-risk analysis to IFC export and transfer to the CMS. The individual prototypes have been made available on the web platform *caupa*[2].

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[2] http://www.caupa.de/projects/zukunftBau