Building Integrity: Classification Beyond Building Parts and Spaces

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ABSTRACT

The effective use of information technology, IT, in the building process requires a common language of well designed classification and coding systems with clear rules for their application. To date, building elements and spaces are the principal concepts submitted to classification for the building sector. A third concept, the interactions between building parts, elements, spaces and system is less considered as an area for systemizing and classification. However, neglecting the interaction problems, which could affect what will be called the *Building Integrity*, BI, causes many negative effects during the building process and operation, *eg*, increased cost, low quality of the finished building and uncertain and vague distribution of responsibility between an increasing number of actors and suppliers of the building process. An analysis of the problem is presented, a few examples are given and a tentative set of principal classification concepts are established. The research is still in a preliminary stage. An indication of a possible place for an implemented IT support system, ITSS, supporting BI aspects in the building process is given.

Key Words

building integrity; building process; classification; information technology; system

CLASSIFICATION

An Evolving Process

Experience from the work on standards and implementation of various systems supporting the building process has shown that efficient use of IT requires a common language of well designed classification and coding systems with clearly defined rules for their application. Large contractors, for example, develop their own corporate standards. During the years classification systems have emerged on the national level too. In Sweden, the BSAB system is used throughout the building industry. The CI/SfB system in Britain plays a similar role (Keijer, 1992). Classification schemes, to be adopted on the industry level, have to be developed in close co-operation with the industry concerned. In addition, it takes a very long time to have an informal standardisation, which could be said to be a kind of agreed classification, fully accepted by all parties

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of the industry. The forerunners of the BSAB-system in Sweden started as early as in the 1940s. This means that we always have to consider the long time required to achieve a fully accepted classification at the industry level in a country or a region, if ever. Therefore research may be most fruitful at company or project level. With time the situation may mature and successful classification at an industry level may take place.

The design and the construction process should have, as primary consideration, the benefit of those who are the end-users of the building as well as of its management during its life-span. This pertains to the building as a whole as well as to its parts. These parts are of two kinds, *viz* the *spaces* and the *physical elements* (Karlsson, 1990).

The classification of spaces relates to the activities that are supposed to take place or, in fact, take place within the different spaces. We have to consider spaces on two different levels, *simple spaces* and *compound spaces*. Compound spaces aggregate single spaces and/or compound spaces of lower levels. Thus, the whole building as an entity can be considered to be a space system, too.

Physical parts consist of larger *elements* such as foundations, external walls, a complete water supply system, and on different levels, piles, bricks, pipes, a specific ground floor external wall, water supply of an appartment, *etc*. Elements can be further subdivided or aggregated in order to establish convenient *work sections* for proper organisation of the construction work. A work section not only defines a part of a building, but also a procedure for its construction can be assigned to it. So, not only a model of the building product is supported by classification; the process, *ie*, the way the building is to be constructed, can also be served by a suitable classification system.

Building Integrity

Building elements and spaces are the basic objects for defining a building as a physical entity and how to operate it. Most of the functional requirements on a building are satisfied by securing the proper design and construction of the separate building elements, such as structural safety, reasonable climate shelter, acceptable indoor temperature, avoiding unwanted smell or noise from adjacent spaces, *etc*.

However, there are in general many inconveniences and problems which show up during the operation of a completed building. The quality assurance system may and should take care of many of the problems such as odour, noise and water leakage. However, modern buildings consist of so many different systems in order to comply with so many different requirements. There seems to be good reasons for addressing, in a systematic way, not only the single building elements and systems in order to fulfil all prescribed and conceivable requirements, but also the interaction between these elements and systems. An integral view of the building should be taken. We will call this view the *Building Integrity* (BI) aspect of the systematisation of the building process and its derivatives, such as classification, building product modelling, electronic data interchange, *etc*.

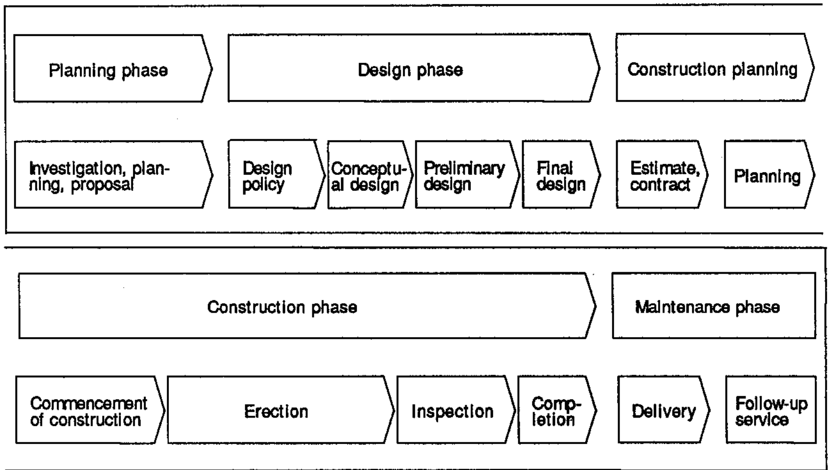

Figure 1. The Building Process. After Bennett *et al* (1987)

We will immediately return to some examples and to building integrity as an aspect to be maintained throughout the entire building process, not just in the client's brief or the operator's files of claims. First a brief theoretical view on the nature of the problem will be taken.

The Building Process

The building process is often seen as a linear process from early investigations to the maintenance phase, see for example, Bennett *et al* (1987) from which figure 1 is derived. The main phases, as a rule, are broken down into sub-phases. We allow ourselves to consider these phases as relatively well structured entities and that the interfaces between the different phases will be the interesting and critical issues. Also, we have to recall that planning and design are activities pertaining to a model of a future building to be erected. The construction phase, on the other hand, is very clearly oriented to producing a real artifact, the building itself. We can use three concepts:

- the product definition phase
- the product manufacturing phase
- the product operating phase.

The first two phases are, in principle, entirely directed towards the third one, see for example, Barnes (1988). Unfortunately, the complexity of the building process distracts the interest of involved parties to more narrow goals within the process itself. Figure 2 depicts some of the major stages of the definition and the manufacturing phases. At the early stages, *ie*, investigations, programming and early design, the objective is the erected building and its use. As we proceed in the design phase, more and more of the activities are directed towards the completion of the design as such and, depending on the organisational form of the process, the construction work. As the process proceeds, the actors tend to direct themselves towards more immediate goals, which may obscure the overall requirements of the completed building in use.

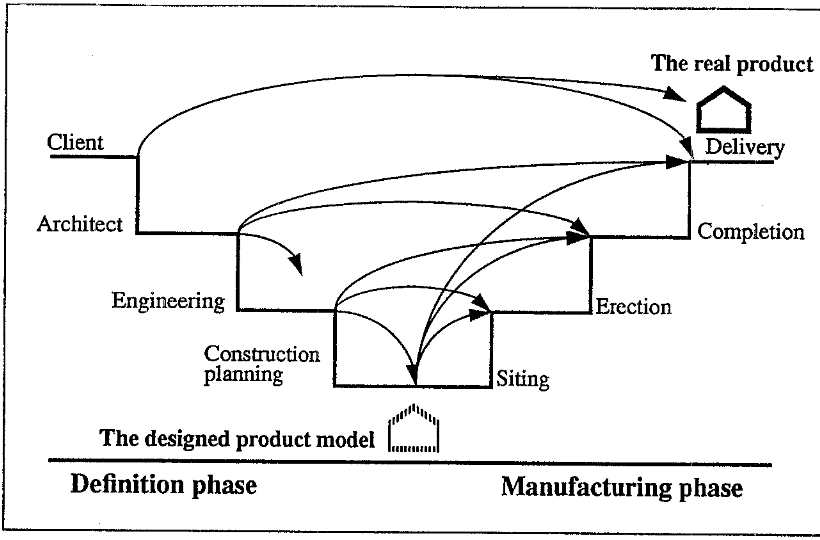

Figure 2. A schematic outline of the building process and the primary concerns of different actors

The final result of the design process, drawings and specifications, aims at describing the model so well that it should be possible to construct the building according to the intentions developed during the definition phase. Basically, the drawings and specifications should imply that the building will have all functions and comply to all requirements that were prescribed from the beginning.

This puts the crucial *transition* from the definition phase to the manufacturing phase into focus. To maintain ideas, intentions, and prescriptions, sometimes not clearly stated, during this transition is a formidable task. The construction planning phase is of utmost importance in order to achieve a final building that will make the client happy. The BI issue is a part of this.

CONSTRUCTION PLANNING

Activities, Resources and Work Sections

The transition from design to construction, from modelling to physical reality, requires much effort and is carried out under a tight time schedule. The interest is concentrated, for the contractor, to the most decisive points of the construction planning, *ie*, (re)billing of quantities, subdivision of the contract, procurement of subcontractors, materials management, site planning and choice of work methods for major building elements. The work is now primarily directed to the building elements and their parts and the different subsystems. Their interrelationships which also have importance and may have been considered in the design phase, tend to be neglected. This negligence not only affects the final building, it may also incur considerable extra costs.

Let us now look at the construction planner's situation a little more closely.

The total manufacturing of a building or a facility of any kind is broken down into conceivable parts (work sections) or *activities* (A) resulting into *finished elements* (D). These activities require *resources* (R) of different kinds, *ie*, goods and material, tools and site equipment, human effort, and information. Sometimes less attention is paid to the difference between the activity and the finished element as a result of this particular activity. Resources required are sometimes seen as a part of the activity. An activity is then like a cook-book recipe where input, process and result are seen as an entity for achieving a building element or a system. Different views lend themselves to different systematic approaches. To start with, the following definitions are adopted.

Resources (products, human effort, etc) are handled and refined on the site through a large number of systematic *activities*. The combination of a set of resources and an activity produces a *finished element*. The total result, the *building*, is presented as the *sum* of all finished elements. In Sweden, the BSAB system is used as the basis for the IT support systems which now are commonly used in the Swedish building industry for handling the planning task in practice.

The definition can be written as a formula

$$\text{Finished Element} \leftarrow \text{Activity (Resources)} \quad (1)$$

or simply

$$D \leftarrow A(R) \tag{2}$$

where $\leftarrow$ indicates an assignment and its direction.
The final result of the manufacturing, P, the very building, is then

$$P = \sum_{i=1}^{n} D_i \leftarrow \sum_{i=1}^{n} A_i (R_i) \tag{3}$$

where D_i is the i:th finished element
A_i is the i:th activity
R_i is resources pertaining to A_i
and n is a large but fixed number for each construction project.

Mostly, R_i may be determined relatively simply. A_i, on the other hand, has to be prescribed so as to achieve the required quality of the finished part. Codes of practice, specifications, design calculations, description of work methods, and checklists support the activity A_i so that the finished part $A_i(R_i)$ can be accepted.

Simplistically we could say, based on the above analysis, that the total building is the sum of all its parts, geometrically placed according to the design drawings; in fact, very similar to a child's play with wooden bricks. There is, however, no reason to state that all finished elements and systems being acceptable, the whole entity, the building, will be satisfactory (see, *eg*, Langefors, 1967). We ought to revise the definition (3) given above. We should rather write

$$P \leftarrow \sum_{i=1}^{n} A_i(R_i) + C \tag{4}$$

where C denotes a complementary product or function.

In fact C, in its turn, consists of a number of different complementary functions, some of them accessible to rigorous analysis and others more intangible. C, so defined, is necessary for having the completed building product accepted by the client and the end-users.

Available methods for construction planning do not give the contractor an absolute guarantee that all information produced in the design phase with the intention to be conveyed to later stages in the building process can be recognised and taken into account. In a particular case it may not be so well described or at a location not expected in the contract. It may be suppressed, still remaining a part of the agreement. The subdivision of building elements or the partitioning for subcontracting may have been done in a way not anticipated at the design and not reflected by the documents.

Building Integrity

Construction is an integrating process. Foundations, building elements, engineering and electrical systems represent the physical parts in this process. As the construction systems develop, more and more functions are delivered ready-made to the site, *eg*, piling, erection of the structural system, floors, bathrooms, security system, climate system, *etc*.

Let us consider all these finished elements and all spaces of the building as "black boxes". We have purchased or constructed certain functions and we do not concern ourselves with *how* they work; *that* they do function according to specifications is the important issue. Thereby, the interest is tied closer to the connections of the elements (spaces, products, systems) than to the very function of each element in consideration.

The total function of the building depends on the functioning of all these elements as independent entities (black boxes) as well as, which is the essence of this discussion, that the connections between all these "black boxes" have been taken properly into account. In theory, all elements of the building may influence all other elements and systems and, thus, have connections, physical or logical, to each other. In practice the number of relationships of interest is more limited. What these relationships are, in general terms, is an aim of our study within this ongoing research project.

To arrive at our final building product P we write:

$$P = \sum_{i=1}^{n} D_i + \sum_{i=1}^{n} \sum_{i=1}^{n} C_{ij} \ (i \neq j) \qquad (5)$$

where C_{ij} is the influence of the i:th element on the j:th element, a relationship that must be in order, otherwise the building P cannot be accepted.

APPLICATIONS

General

Three main areas of application of a BI classification approach have been recognised, *viz*:

- geometric modelling of connections
- classification of mistakes, faults and malfunctions
- distribution of responsibility between different actors at internal boundary surfaces (connections).

Modelling of connections comprises a number of technical and managerial problem areas:

- intelligent support for the representation of connections of CAD systems
- structural behaviour and dimensioning at connections between members and at supports

- heat transmission at complicated geometries
- pictorial and literal instruction on site for novel or uncommon work practice
- quantity billing.

Concerning *classification of mistakes, etc* and feed-back of experiences, the hypothesis is that many cases of damages or malfunctions could be referred to the interaction between materials, elements, or systems, not primarily to a single material, *etc*.

Finally, with the increasing number of different actors on the site - specialists, sub-contractors and suppliers - the complexity of the boundaries, physical and logical, between the undertakings of these actors tend to increase and methods of dealing with a multiplicity of *interacting responsibilities* will be demanded.

Examples

Two simple examples from practice will describe the principle. Figure 3 depicts a section of a stairwell with a landing. Neither the sub-contractor who produced the concrete stairwell nor the supplier of the staircase provided the support for the landing. In addition, nothing explicit could be found in the design specifications, which could clarify who should have taken the responsibility for the support. The situation resulted in significant problems at the site and additional costs which someone had to absorb. The problem should have been identified at the procurement of the sub-contractor for the stairwell, at the latest. It might have been anticipated already during the structural design of this particular part of the building.

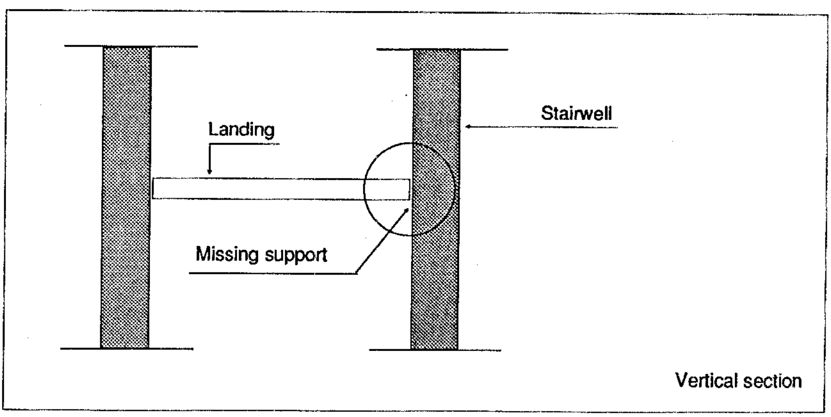

Figure 3. Connection between a stairwell and a landing not properly defined from a BI point of view

The other case, figure 4, is a mistake made at the site. An inspection plate is moved from one side of an installation shaft to another. Obviously, the reason was to avoid destroying the tiles of a bathroom wall and move the opening to a less vulnerable surface. What was not realised was that the purpose of the plate was lost. All pipes were not any longer inspectable from the new position of the opening. The design and the drawing were all right. The reason for the selected location was not, however, communicated.

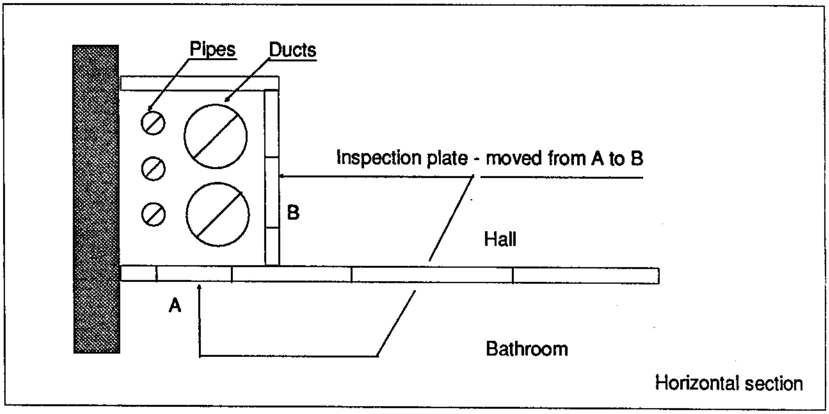

Figure 4. An inspection plate was relocated during the construction phase. Its purpose could not any longer be fulfilled from its new position

In Bertfelt *et al* (1992) some thirty cases are presented, all of them showing problems encountered in practice and related to different parts of the building process. In the ongoing project a large number of BI problems, simple ones like those presented and more complex are collected.

Principal Classifying Entities

When analysing different BI phenomena we have found, tentatively, the following concepts to be used as independent or nearly independent classifying entities. They are shown in figure 5 in a multidimensional co-ordinate system. Table 1 gives examples of the phenomena that could be referred to each classifying entity.

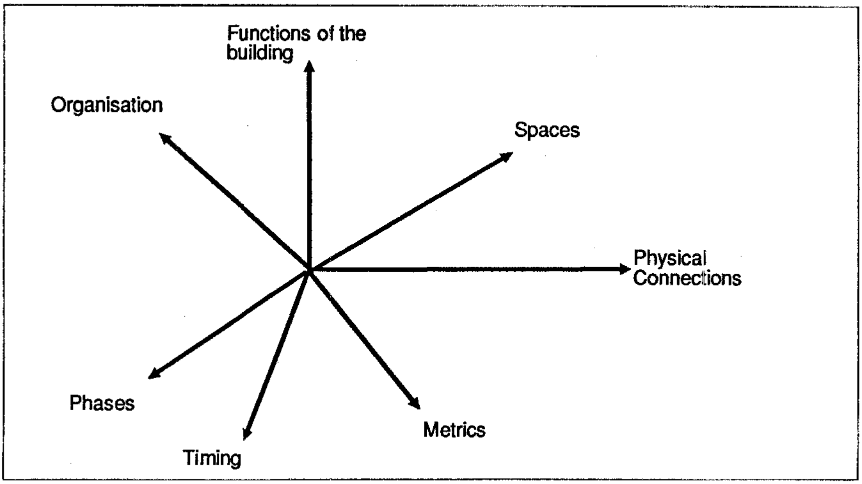

Figure 5. Tentatively adopted classifying entities to be used in BI analysis

Table 1. Parameters for different classifying entities (examples).

Functions examples: - durability - user-friendliness - load-carrying - energy conservation - structural stability - noise insulation - heat comfort - air comfort - climate protective - humidity insulation - maintenance (cost reduction) **Spaces** examples: - spaces according to industry standard - compound spaces **Physical connections** examples: - connected elements - elements to spaces - spaces to spaces - systems to elements - systems to spaces	**Metrics** examples: - geometrical relationships - position - relative distances - tolerances - fitting **Timing** examples: - time of start (point of) - inspection time - relatime times (before, after) **Phases** examples: - when a problem can be anticipated - when a problem can be remedied - when a problem causes damage or cost **Organisation** examples: - entrepreneurial form - procurement form - contract conditions

An IT Support System

The work in this area is still in its infancy. As said in the introduction, an ITSS based on a BI approach would more readily be implemented on a company level, starting on a small scale, rather than on an industry level. The classifying attempts serve, in the first place, to structure the BI problems. Arriving at a final classification on the industry level in the end should be left out of the discussion for the time being.

An BI-ITSS could be implemented in a company on two levels depending on the present integration of the IT Support systems as a whole in the organisation in consideration.

A company with a functioning system for establishing building product models, BPM, for major projects could connect a BI-ITSS to it. For a particular case the BPM is reviewed and possible interactions between elements, materials, systems and spaces which could cause BI-problems according to pre-programmed checklists are sorted out. These results are made available to the actors of the different phases of the building process, from design to operation, and are presented to them in effective ways.

Table 2. Tentative specification of parameters of classifying entities for the two cases given in figure 3 and 4.

Classifying entities	Case 1 (fig.3)	Case 2 (fig.4)
Functions	load-carrying	maintenance inspection requirement user-friendliness
Spaces	stairwell	duct shaft bathroom
Physical connections	landing/wall	plate/wall
Metrics	support length position tolerances	position size
Timing	from: structural design to: procurement	from: design (arch./HVAC)
Phases	anticipated: design remedied: construction cost: construction	anticipated: design remedied: construction cost: operation
Organisation	clients consultant main contractor sub-supplier	main contractor sub-contractor

On a lower technology level a BI-ITSS will be utilised as a stand-alone system with a data-bank of "good practice" which could be used by designers and construction planners in order to be notified of possible BI problems. In this case, in principle, the difference is not too big from an ordinary computer-based consultant system (expert system). Such a system has to comprise knowledge acquisition facilities, a knowledge base with domain rules and facts, an inference engine and a user I/O facility, which, in all, define the principal components of a knowledge based system, see, for example, Dym and Levitt (1991).

Figure 6 depicts a system chart which includes both situations mentioned. In fact, even in an advanced system environment BI-ITSS will be non-integrated when initially introduced.

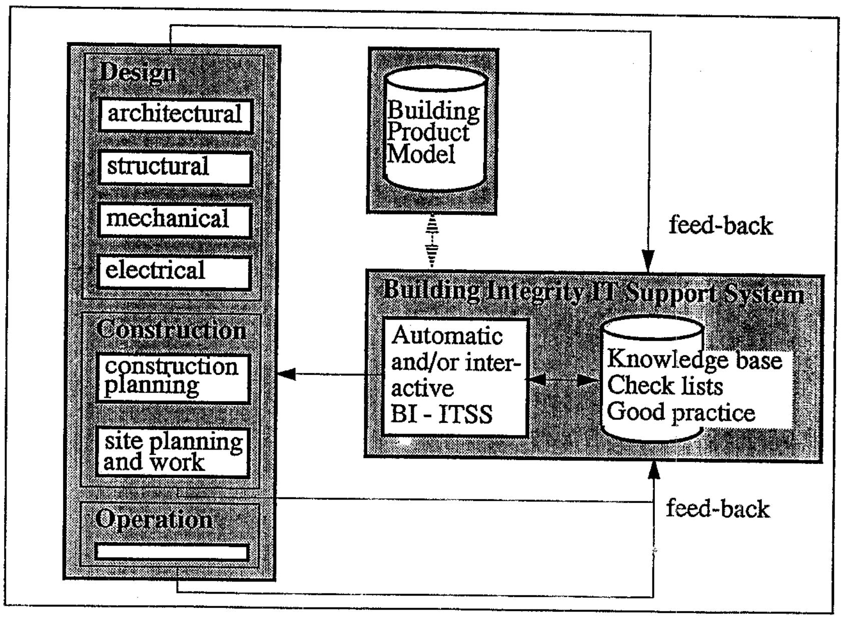

Figure 6. An BI/IT support system and its location and use through-out the building process. Both a stand-alone and an integrated solution with connection to a BPM viable

CONCLUSIONS

The need for a concept to handle different types of interactions during the building process, technical as well as organisational, has been demontrated. Systematisation and, in the future, a classification, even on an industry level, will emerge. The treatment has shown a possible theoretical approach to a general handling of building integrity problems and has suggested how to implement the ideas proposed into an IT support environment.

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