BUILDING INTEGRITY - INTERACTIONS BETWEEN BUILDING PARTS, SYSTEMS AND THE ACTORS OF THE BUILDING PROCESS

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Abstract

Many of the problems concerning poor effectivity, low quality and increased cost in the building process pertain to the area of interaction between building parts, elements, spaces and systems. The industrialisation of the building industry requires a more profound understanding of these interactions. An increasing number of actors and suppliers are involved in the building process which implies interactions related to the organisation of the process. Thus, the interaction problems do not confine themselves to physical parts and technical issues. The organisation of the process, responsibilities and liabilities of consultants, subcontractors and other actors contribute to the growing implications of the variety of interactions that constitute the problem in its whole. An analysis of the general problem, which has been addressed as ***Building Integrity, BI****, has commenced. From a systems design point of view, BI is related to the ongoing research on building modelling, which is discussed briefly.*

1 INTRODUCTION

1.1 THE PROBLEM

Building Product Models, BPM, has emerged as major research field during the last five years, *e.g.* [Björk, 1993], [Eastman, 1993] and others. The principal achievement by using the BPM approach in comparison with traditional CAD system is the notion of object orientation. CAD systems are, generally spoken, line or drawing oriented. A line or an ordered set of lines does not mean anything beyond just denoting a line connecting two points in space. The BPM models consist of objects denoting physical building objects, to which attributes of different kind could be assigned, including entities such as size, form and location, which in turn could be used for generating pictorial views of the object. The attractiveness of BPM pertains very much to the close relationship between the physical object in the real world, let it be a floor, a water supply system, foundation or an entire building on one hand and the data of the construction process of that object on the other hand. Object oriented modelling and BPM is, thus, very much related to each other.

More recently it has been recognized that a complete building product model may be difficult to manage, both conceptually and practically at the implementation stage [van Nederveen and Tolman, 1991]. The concept of a *kernel* model and *application* models for different *views* of the building has been introduced and is illustrated in figure 1. With a view is understood a specific aspect or function of the building, *e.g.* the load-carrying system, the energy conservation system, the distribution of spaces and floors, *etc.* So far, however, no basic general principles have been established for how to distribute object between a kernel and the various application dependent sub-models.

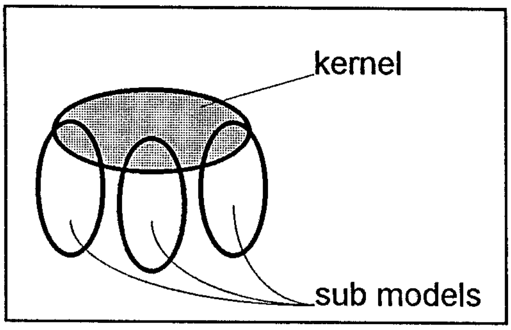


Figure 1. Kernel and application models, as sub models.

Further the BPM is, in general, oriented towards later design phases, where the building becomes fully defined as a model, and towards the construction planning phase. So far the BPM approach has had little to offer the early design phases. For the operation phase of the finalised building at the other end of the chain of the process, emerging classification of spaces and whole building may contribute to a fruitful development of BPM for this latter phase of the process. It may be stated, however that BPM, presently, is based on a view very close to that of construction planning. If not very profound restructuring of the model, in particular the kernel model, can take place considering other requirements than those from the construction planning phase, it is very likely that problems encountered in the building process today related to other phases of the process will be difficult to avoid in a process based on current building product models.

What is then the basic view from the construction planning aspect? Roughly spoken, it is a list of work sections, their volumes, areas or unit prices and a list of equipment and their unit price. We obtain very quickly a sum of a vast number of multiplications of amounts and prices. The totality of objects of which the building consists is assumed to form the entire building, including all requirements both functional an technical which have been considered during the design phase. We know that this is not the case. Two typical practical cases illustrate this, see figure 2 and figure 3.

These two cases show clearly the type of problems we very often encounter in practice. The problems pertain, in general, not to a single object of the building nor to a single actor. The problems very often have their roots in interactive combinatory situations which temporary or permanently run out of control. Small errors, *e.g.* missing communication between actors or missing obvious details in a specification may generate serious faults later in the building process. Present approaches of BPM seem not to include these types of phenomena directly, although it may be asserted that a certain model could include just any specific case, like these shown. To cover these problems in general another approach will be necessary. The so called *building integrity, BI,* problem [Keijer, 1993] has been assigned to this aspect of BPM. It is also clear from these examples that BPM considered as a pure description of the designed and/or produced building will not be sufficient. The *process* for having the building designed and contracted will also have a profound influence of the significance of the *BI* problems in given cases.

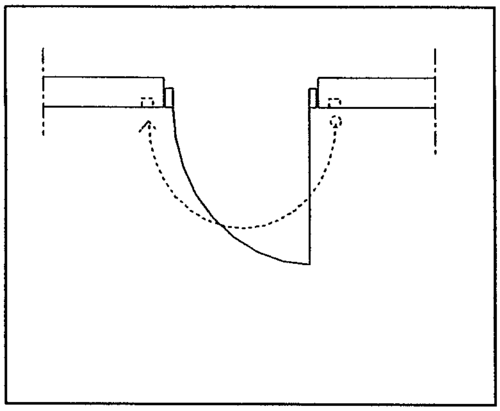


Figure 2. The light switch has been placed at the wrong side of the door-opening. One single mistake at design causes a multitude of costly errors at construction.

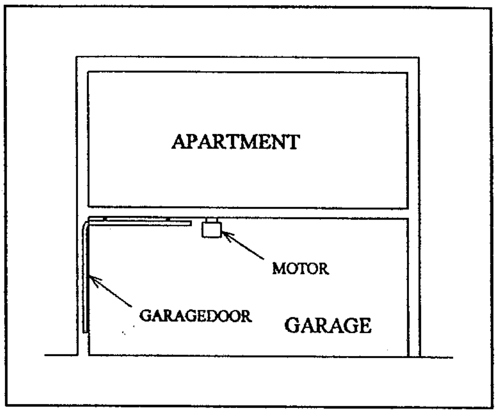


Figure 3. The noise from the garage disturbs the above apartment.

1.2 RELATED FIELDS

1.2.1 Building defects

Two typical building defects are shown in figure 2 and 3 above. Figure 2 illustrates a very simple kind of mistake, presumably depending on lack of coordination between the architect and the electrical designer. The reason behind the defect shown in figure 3 is more profound and could be classified as a sort of knowledge (or lack of knowledge) problem. It is not enough to consider the vibrating from the motor but, at the same time, identify the function of the adjacent space as a living (or a sleeping) room of an apartment, *i.e.* the combination of these two circumstances forms the problem.

The starting point of the project was some 30 descriptions of different defects, related to assumed *BI* problems which all incurred cost for remedy [Bertfelt & al, 1992]. In an analysis of these defects it was recognized that they emerged at different phases of the building process and often depending on insufficient coordination between different actors of the process. Defects related to the transfer of pipes through building elements and problems depending on fire protection measures seemed frequent from these problems studied.

The building integrity aspect is related to building defects in general. This will be further elaborated below.

1.2.2 The feed-back problem

If the actors of the building process had enough experience and sufficient common knowledge, the number of problems during the construction and the number of defects of the completed building would be very much reduced. The number of crucial situations that can emerge in a building process is large. Many emerging situations are new for the actual actors engaged. Many of these situations will seldom be anticipated, either.

Many problems with feed-back relate to the information transfer between the designers and the construction planners. The designers are seldom fully aware of many of the mistakes they cause. Often they are cut off from the subsequent process after having completed their design tasks. Feed-back could be improved if designers could participate at inspection. Many of the defects are detected after the construction is completed, but feed-back from operation of the building is in most cases insufficient. The responsible parties of the design and construction phases never become really aware of the mistakes with long-term consequences.

The building defects can be classified according to feed-back as follows, although the list is by no means exhaustive:

- defect, well-known in advance; in spite of that repeated,
- the same defect in (slightly) different circumstances,
- defect due to change of responsibility (change of organisation),
- defect due to new materials,
- defect due to new combinations of building elements or components.

Although a good feed-back system may be defined and implemented, it will always be very difficult to anticipate new types of problems. The defects, their causes and their secondary effects should be analysed from a more generic point of view. A classification of building defects and failures should be undertaken and seems to be very much needed.

1.2.3 Complexity

The building process is often said to be complex. The object for the process is a large, costly artifact, *i.e.* the building itself. It consists of thousands of thousands pieces to be put together. Many actors participate in the process, planners, designers, contractors, suppliers, the interrelationships of which are difficult to define fully.

Complexity has recently emerged as an area of scientific research of its own, see *e.g.* [Freedman, 1992]. The acknowledgement of chaos as a natural state [Glieck, 1987], the theory of economics of increasing return [Waldrop, 1992] and the theory of complex dynamic systems, including human activity systems [Checkland, 1986], [Senge, 1992], all contribute to a widened view of human-system interaction and the limitation of deterministic systems.

The nature of the building process, characterized by sparse resources for planning during short periods of times, poor feed-back from previous experience, and heavy demand on cost control, implies that complexity should be regarded as an intrinsic property of building process. When studying the process, or a part of it, this fact must be recognized and given appropriate attention. Checkland [Checkland, 1986] distinguishes between four general systems, *i.e. natural systems, designed physical systems* (e.g. buildings), *designed abstract systems* (*e.g.* information transfer procedures of the building process) and *human activity systems.* Checkland emphasised the difference between the three former types of systems in relation to the fourth, the human activity system. In the latter case, the system is not independent of the actors, who in this case are *parts* of the system. The building process should be regarded as such a human activity system. To a large extent, such a view seems to be necessary for a fruitful treatment of building integrity as a general problem. This view is supposed to be one of the influencing ideas for the present work.

1.2.4 Axiomatic design

The principle of axiomatic design developed by Suh [Suh, 1990] proposes a general procedure for the design process. It should be noted that the word *design* should not be interpreted as engineering design only, although the source of the concept has emerged from the engineering field. According to Suh the principle is equally applicable to sociological and economical systems. Thus, to the building process, or a to part of it, the principles of axiomatic design could be advantageously applied.

Axiomatic design is based primarily on two fundamental general axioms, *i.e. the independence axiom*, which prescribes independence of governing functional requirements on each successive level of the design procedure, and *the information axiom*, which states that minimum necessary information, provided the independence axiom is fulfilled, yields an optimal solution. These two axioms should have significance also for building integrity as a concept.

The first axiom puts requirements on the information structure for the building integrity phenomenon. Independence, orthogonality, of its principle constituent parameters should be maintained. The so called classifying entities [Keijer, 1993, p. 144], see also figure 7, have been proposed according to such a requirement, albeit not strictly referring to it. These entities will be further examined in view of this axiom. It should be noted that the axioms have implications both on building objects/spaces, *i.e.* physical entities, and on process oriented concepts.

The second axiom, the minimum information axiom applied to information systems development, could be seen as a generalisation of the normalisation procedure originally developed by Codd for the theory of relational databases [Codd, 1970], [Finkelstein, 1989]. The axiom will define a kind of design criterion for a final conceptual schema for the *BI* aspect as a whole.

1.2.5 Bremmermann's limit and building integrity

In [Keijer, 1993, p.141] a sum of sums was formally developed for characterising the total possible effect of building integrity:

$$BI = \sum_{i=1}^{n} \sum_{j=1}^{n} C \quad (i \neq j) \qquad (1)$$

where BI is the total building integrity as a sum of interactions between all constituent building elements

and C_{ij} is the influence of the i:th element, space or function on the j:th element, space or function.

The number of elements, components, spaces, and functions, is very large also for ordinary buildings enterprises. A modest value is 10 000 that implying 100 million possible interactions. Not covered by equation (1) is the effect of three or more interacting objects and their possible contribution in combination to a BI phenomenon. Virtually no upper limit could be defined. In reality, however, the number of actual interactions is very much smaller. This fact calls for an efficient strategy for the categorising and the classification of BI problems.

A more exiting argument for limiting the number of dependencies of a complex structure is given by Suh [Suh, 1990, pp.16-17]. He refers to the so called Bremmermann's limit, which, according to Suh, limits the number of storage variables at a time to 270 for a complete factorial design, even if the total mass of Earth was transformed into electrical energy and used for storing the necessary information! In many design situations, says Suh, the total design number of variables involved may be larger than 270. This statement should be equally valid for building design. In its deepest consequence, this low figure may generally restrict the practical implementation of theoretical data structures where the number of variables in a typical case is large. This could have profound impact on various problems not only the BI problem as it is interpreted in this work.

2 THE OBJECTIVE OF THE RESEARCH PROJECT

2.1 BUILDING INTEGRITY

According to the discussion, so far, some areas of specific interest within the framework of *building integrity* could be pointed out, *i.e.*

- interactions between building systems, elements and components,
- interactions between actors of different professions,
- transfer of information from phase to phase of the building process.

It is easy to describe and analyse a specific practical case like those related above. To proceed from specific situations to more general aspects there will be a need for systemisation like modelling and classification.

2.2 IT-SUPPORT - FOR WHICH PARTIES?

The building process can be regarded as a process from the early planning phase to the maintenance phase, see *e.g.* [Bennett & al, 1987] from which figure 4 is derived. During the design phase, a lot of information is created and distributed among the actors of the process. 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 this phase. An IT supporting system for the *design phase* could help the actors to coordinate the BI relevant information of the documents. As reported below, more than 50 % of the defects arise from the design phase which indicates the range of possible improvement.

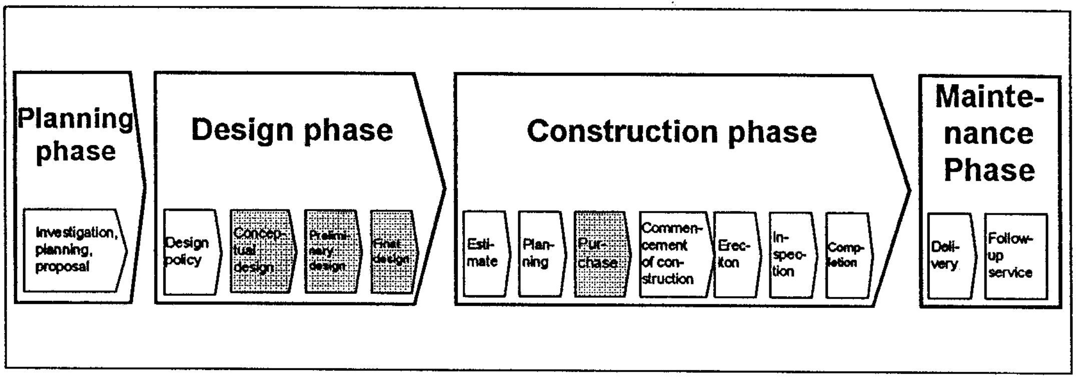


Fig 4. The main actors in the building process, after [Bennett & al, 1987].

The design information must be transferred to the different sub-phases of the construction phase. Ideas, intentions and prescriptions are seldom completely documented. Experiences from different enterprises indicate that the information transfer to the *purchasing function* often is neglected.

The research work will then primarily address the two specific functions shaded in figure 4, which have been selected being of particular interest for the BI aspect, *i.e.*

- the design phase (in particular the later parts of it),
- the purchasing function.

2.3 A DECISION SUPPORT SYSTEM

An IT support system for *BI* problems, BI-ITSS, has been discussed tentatively [Keijer, 1993]. A BI-ITSS could be implemented in a company on either of two levels depending on the current integration of IT .

A company with a functioning system for establishing building product models or similar integrated models could connect a BI-ITSS to it for major projects. 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 different phases of the building process, from design to operation, and are presented to them in effective ways.

On a lower technology level a BI-ITSS could be utilised as a stand alone system with a database of "good practice" which could be used by designers and the purchasing function in order to be notified of possible BI problems. In this case, in principle, a support system of this type is very similar to 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.

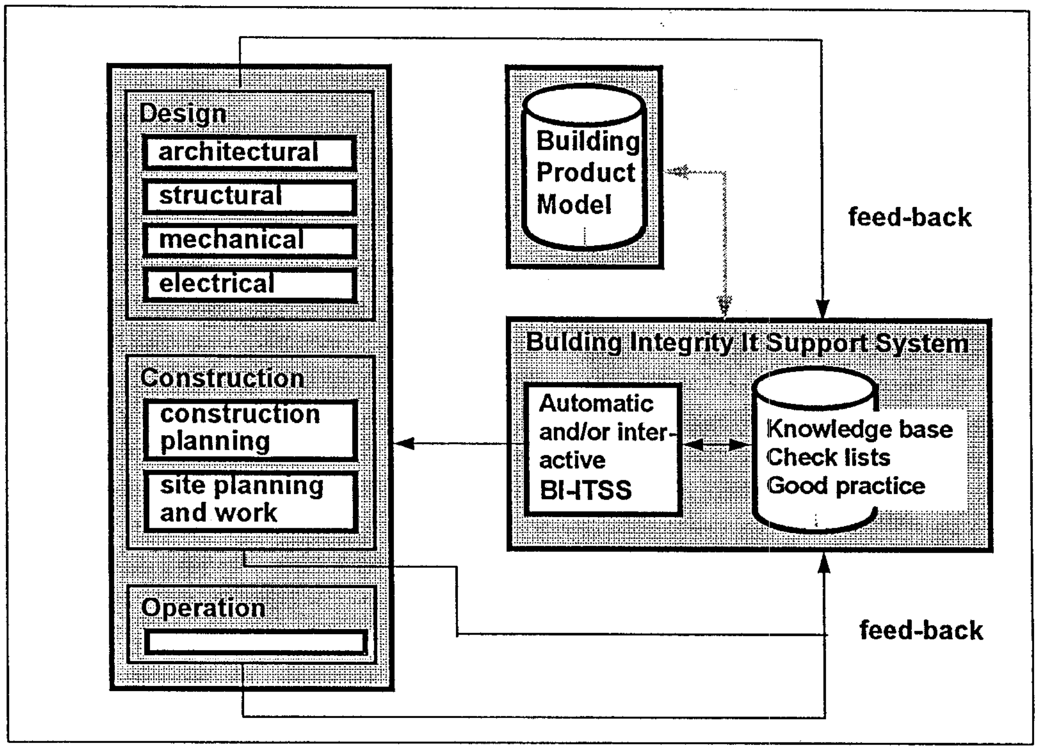


Fig. 5. An outline of a BI-IT Support System, from [Keijer, 1993].

2.4 HYPOTHESES TO BE VERIFIED

The building integrity problem, with the adopted interpretation is well-known as a general phenomenon of the building process. The concept, however, suffers, for the time being, from lack of precision. The project in progress has a number of objectives, one of these is to give unambiguous, precise and effective definition of the phenomena as such.

Thus, the first hypothesis is that such a precise definition exists and can be formulated. In close relationship with the definition of the BI phenomena is the proper structure and the classification of it. The first hypothesis includes the assumption that such a classification can be found and developed

Secondly, the building integrity problem, once defined, should be possible to tackle within the building process. What parties of the process have the possibility to foresee the emergence of BI-problem, who are able to detect them and who have to take care of them and remedy them? The second hypothesis relates to the possibility of defining appropriate measures for the actors of the building process so as to check, manage and control problems related to the building integrity problem.

Thirdly, a further hypothesis to be verified is that it should be possible to establish an information technology based support system, ITSS, adapted to and attractive for the actors of the building process taking care of BI problems of the process. Specific attention will be paid to the adaptation of a BI-ITSS to ongoing development on building product models and their applications in practice.

3 FAULT AND MISTAKES IN THE BUILDING PROCESS

3.1 BUILDING INTEGRITY RELATED TO BUILDING DEFECTS.

Almost every building can be regarded as a prototype, as they seldom are repeated in long series. Building elements and components, on the other hand, are the same from building to building. Their combinations vary, and the number of ways how the elements can be linked to each other is very large. The actors responsible for these links vary and the actors also participate in the process independently of each other and often at different phases. It means that information must be transferred between these actors both in the same phase, *e.g.* actors within the design phase, and between different phases, *e.g.* from the design phase to the actors on site.

Building defects as a problem is well-known both in practice and research. The defects, however, has not, so far to any noticeable extent, been related to the view defined as building integrity. But it can be easily asserted that building defects and BI problems very much are two sides of the same problem They address the same problems of the building process, *i.e.* *w*hat problems do they cause, when do they arise (in which phase) and what do they cost?

3.2 BUILDING DEFECTS

The literature concerning building defects is ample. An extensive survey has been carried out in Sweden [Bergström, 1989], which covers about 60 references including many international investigation, *e.g.* [BRE, 1987], [ASCE, 1985], [Augustsson & al, 1989]. In general, the defects are classified according to how they are detected, *i.e.* what effects do they cause, *e.g.*

- bad functionality,
- high cost for maintenance,
- early need for repair,
- bad environment for living and working,
- abnormal ageing (aesthetics), but still usable,
- exceptionally short technical endurance.

Many defects are detected already during the erection phase. Albeit this type of mistakes not causes problems for the end-users of the building, they are often costly. Mistakes during the building process involving injuries, even deaths, should be included as defects, principally caused by poor organisation of the building process.

Bergström reports the following distribution of defects related to different phases of the building process, table 1.

Design phase	51 %
Construction phase	26 %
Material	10 %
Other	13 %

Table 1. Distribution of defects in different phases [Bergström, 1989].

The total cost for the building defects differs from project to project and between different types of buildings. From the studies reported it is shown that cost for rework *within* the building process is 2.5 - 5.9 % of the production cost. If the cost during the life-time of the building, depending on defects and mistakes, is included the figure will be higher. For example, it is reported that for residential buildings, the increased costs for maintenance are estimated to 3 % of the construction cost, which will be the equivalent to 12 % increased maintenance cost.

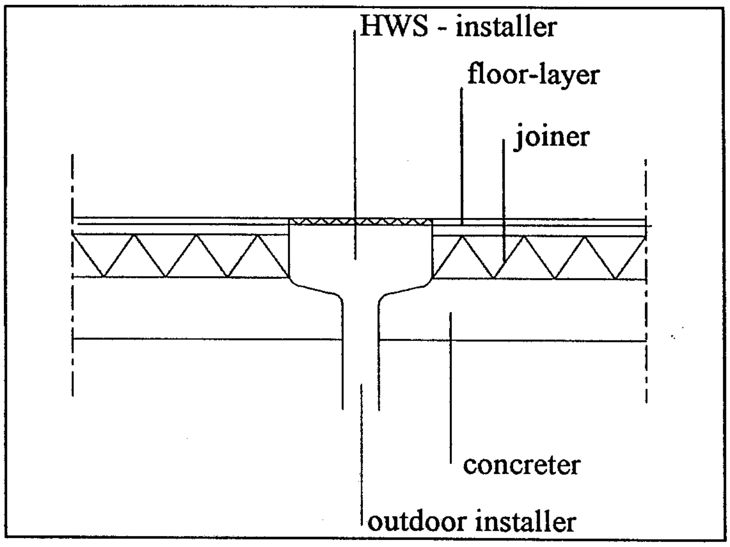
Classification of building defects are primarily based on building elements. From the literature, in general, it is difficult to find out if a specific defect should be related to a specific element and a specific actor, or if it should be referred to two or several physical elements or interacting parties of the building process. In the latter case only, we have BI-problem. From the studies it is obvious that a substantial part of the defects depends on insufficient coordination of actors and that, roughly, 25 % - 50 % of the defects could be recognized as BI-problems.

From the literature it is also difficult to find out what really is the primary cause for a specific defect. It could be bad workmanship, carelessness, insufficient knowledge of the actors, lack of information from other actors, insufficient basic knowledge in the construction field or incorrect information in building codes and suchlike.

The principal causes reported are the following,

- lack of coordination between participating actors,
- the organisation and type of tendering,
- lack of feed-back, *e.i.* earlier mistakes are not taken into account,
- insufficient control, lack of system for quality assurance,
- lack of information, existence of information gap,
- inappropriate education system,
- inappropriate building codes,
- use of new materials construction without enough prior experience,
- fuzzy responsibility boundaries.

Many of these causes are inherently related to building integrity. A typical example of the first cause listed is a draining gutter located in a bathroom, where not less than five different workers have to coordinate their jobs, see figure 6.



F*igure 6. Five different workers have to be coordinated for a draining gutter.*

3.2 FAILURE MODE AND EFFECT ANALYSIS

From a prospective IT supporting system it should be expected to be notified where combinations of building elements, systems or components could cause a BI-problem. It seems probable that there may be too many indications and many of these will be insignificant. A system must be able to select and address problems which, with reasonable probability, will cause building defects of some significance.

A general method, *failure mode and effects analysis*, FMEA, [Mårtensson, 1993] could be helpful for analysing the requirements on a BI Supporting System. Roughly, FMEA analyses the problem by asking questions and from the answers a risk coefficient is calculated. FMEA can be used both for the design phase and for the construction phase.

For every building element or activity an estimation of a coefficient, 1 - 10, for the following three questions A, B and C, is made.

A: The probability for the occurrence of a defect.
B: The probability for an occurred defect to be detected.
C: The seriousness of the effect of defect.

A risk coefficient, *RC*, is calculated:

$$RC = A \cdot B \cdot C \qquad (2)$$

For a high value of *RC* the presumptive defect should be examined and countermeasures considered. The same applies if one or more of the three constituting factors, A, B and C, show extreme values. The principle of FMEA will be examined more in detail and, if applicable, it will be adapted to the BI phenomenon under discussion.

4 A CONCEPTUAL MODEL FOR THE BI ASPECT

4.1 STARTING CONSIDERATIONS

It is important for a prospective BI support system to be able to be adapted or included in a general building product model, BPM, and also to a model of the construction process. Such a system could be regarded as an extension of a BPM. A possible way is to regard the BI aspect, in a given case, as a set of new objects with relationships to objects of the BPM and of the process model.

4.2 A PRODUCT MODEL AND A BUILDING PROCESS MODEL

As discussed above, for BI problems it is unsatisfactory to address only the physical objects and their interactions. It is equally important to have the building integrity aspect included in an overall framework of the building process. The process and product models should be linked to each other, as suggested by, *e.g.* [Karstila & al, 1991], [Tarandi, 1993] and as in a newly released proposal for the Swedish BSAB-system [BSAB 9X, 1993]. Figure 7, from [Keijer, 1993], indicates this with a number of classifying entities which partly are related to a product view and partly related to a process view.

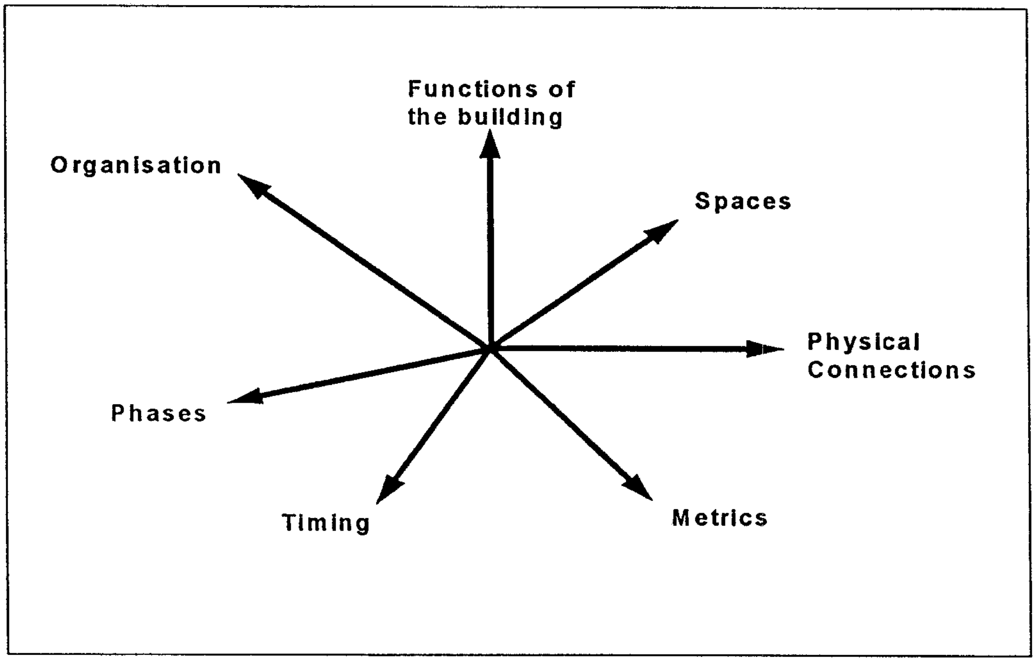


Figure 7. Tentatively adopted classifying entities to be used in a BI analysis. From [Keijer, 1993].

4.2.1 The Building Product Model

A tentative conceptual schema is depicted in figure 8. The schema illustrates only the most interesting objects from a BI point of view. The *building objects, e.g.* walls and doors, are the principal parts of the BPM. The totality of all building objects is often regarded as the *building* itself. In principle, the BI aspects is then neglected. The building objects can be parts of different *systems,* like the ventilation system and building objects can be parts of other building objects. For more detailed specifications, building objects can be broken down into building details. Building objects belong to different classes described as *building parts, e.g.*, in the Swedish BSAB code. The *building part type* is a subclass of building part. The part type code gives the possibility to describe the building object at different detailed levels as it has been used, *e.g.* in the MCAD-system [Paulsson & al, 1993]. Relations between building objects like connections, both technical and functional, and other BI objects are described below.

4.2.2 The Building Process Model

From the design phase, information is to be transferred to the construction phase. This information includes drawings, specifications and bills of quantities. The information is used for, *e.g.*, cost estimation, planning, purchasing and erection. The building process model, BProcM, see figure 8, depicts some main objects which primarily could be used for cost estimation, planning and purchasing.

A building object is created through one or many *product results, e.g.* formwork, reinforcement and casting. The product result is produced by *activities,* which use *resources* like *manpower, machine resources and materials.* The activities have a point of start and a point of completion. Normally the activities are too detailed when using them for planning. Thus, related activities can be grouped together as *planning activities. Type activities* classify the activities of the building process.

Contractors have elaborated *methods* for various activities. A method consists of unit *resources for manpower, machines and materials* and a description for a *type activity.* Each *resource type* may include a unit price which implies the possibility of summarising the *cost* for a product result. By connecting type activities to a building part type it will be possible to transform information from the design phase to different support systems in the construction phase, *e.g.* in Sweden as in the MCAD system.

One idea could be to include BI phenomenon as attributes to the methods of different type activities. Some of the BI attributes could be a part of information related to materials as well. More in accordance with the *principle of axiomatic design* would be to acknowledge the building integrity aspect as an entirely different view of a building. A *dual view* [Bertfelt & al, 1992], not further elaborated here, could be adopted. With such a view the building is seen as an assembly of physical parts on one hand and as an of assembly of nodes with elements connected to these nodes on the other.

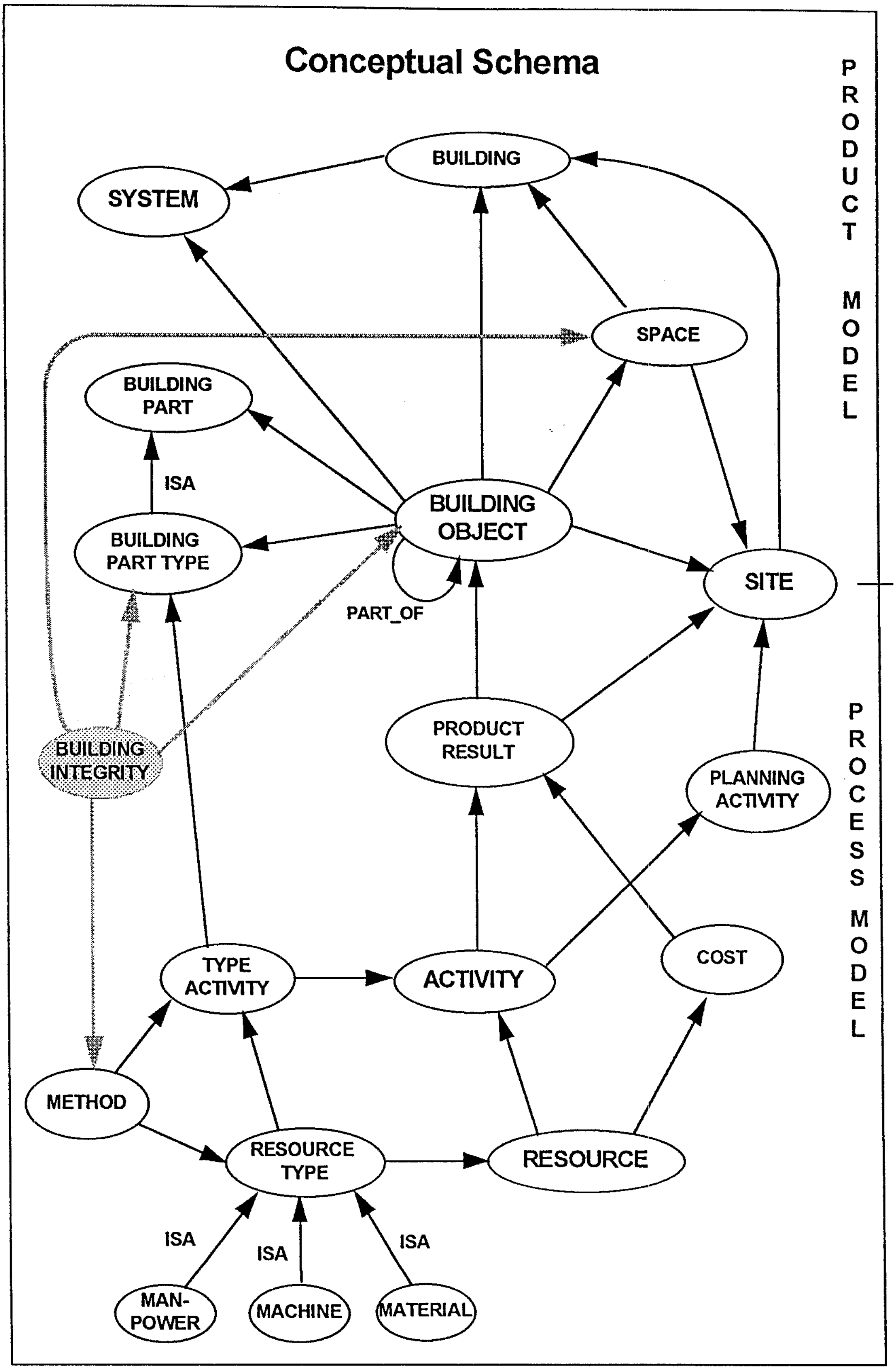


Figure 8. Building product and building process model, including the building integrity aspect. A tentative outline.

4.3 A PARTIAL BI PRODUCT MODEL

A tentative outline concerning some principal *BI* objects and their relationship is shown in figure 9. The *building part type* is completed with objects describing a number of possible influences between building objects. The interaction can be a *physical connection* of different subtypes as *border, feature, and attachment. Border* means a common connection between two building objects without any complications, *e.g.* between two kitchen cabinets. *Feature* describes a more complicated connection where the connections are dependent of each other, *e.g.* between walls or between beams. Attachment stands for fixing building objects to each other by bolts, welding *etc.* Similar to the physical connections, it should also be possible to regard functional connections or more generally *functional influences, e.g.* fire, sound or moisture problems. Another important view is the required area for a building object including *service space*. There must be place enough to accomplish the connection itself and for many object there must be a service area and a free area for using the building object, *e.g.* a free area in front of a washing machine.

Related to different building objects there will be found information that indicate presumptive BI problems as described above. When combining two or more of these building objects some interactions may arise, described as the *BI interaction* objects. These objects can be used to control the presumptive BI problem. The *BI interaction* can be a physical *joint* or be related to as a *function.* The *risk coefficient* offers the possibility to confine the treatment to significant indications, as discussed earlier.

A way to give BI support during the construction phase is to develop relationships between *BI interactions* and *methods* and *materials.* The purchasing function could be given important information in dealing with suppliers, outlined as a relation in the schema between BI interaction and material. A method describing the type activity and resource types assumed to be completed with BI interaction information, which obviously could increase the awareness of BI problems.

Figure 9 indicates possible links in a prospective conceptual schema for a systematic handling of some BI problems. It should be emphasised, however, that the schema is very preliminary and will be continuously developed.

5 WORK IN PROGRESS AND CONCLUDING REMARKS

The work presented is in progress. Building defects and failures of different kinds will continuously be recorded and classified in order to cover a broad scope of BI problems. The generalisation and classification of these problems continues.

As reported the need for IT support for two specific functions of the building process, the design management and the purchasing function of the construction planning will be examined specifically.

An information structure, i.e. conceptual schema, will emerge successively. The relations to ongoing practical applications of building product models will be focused.

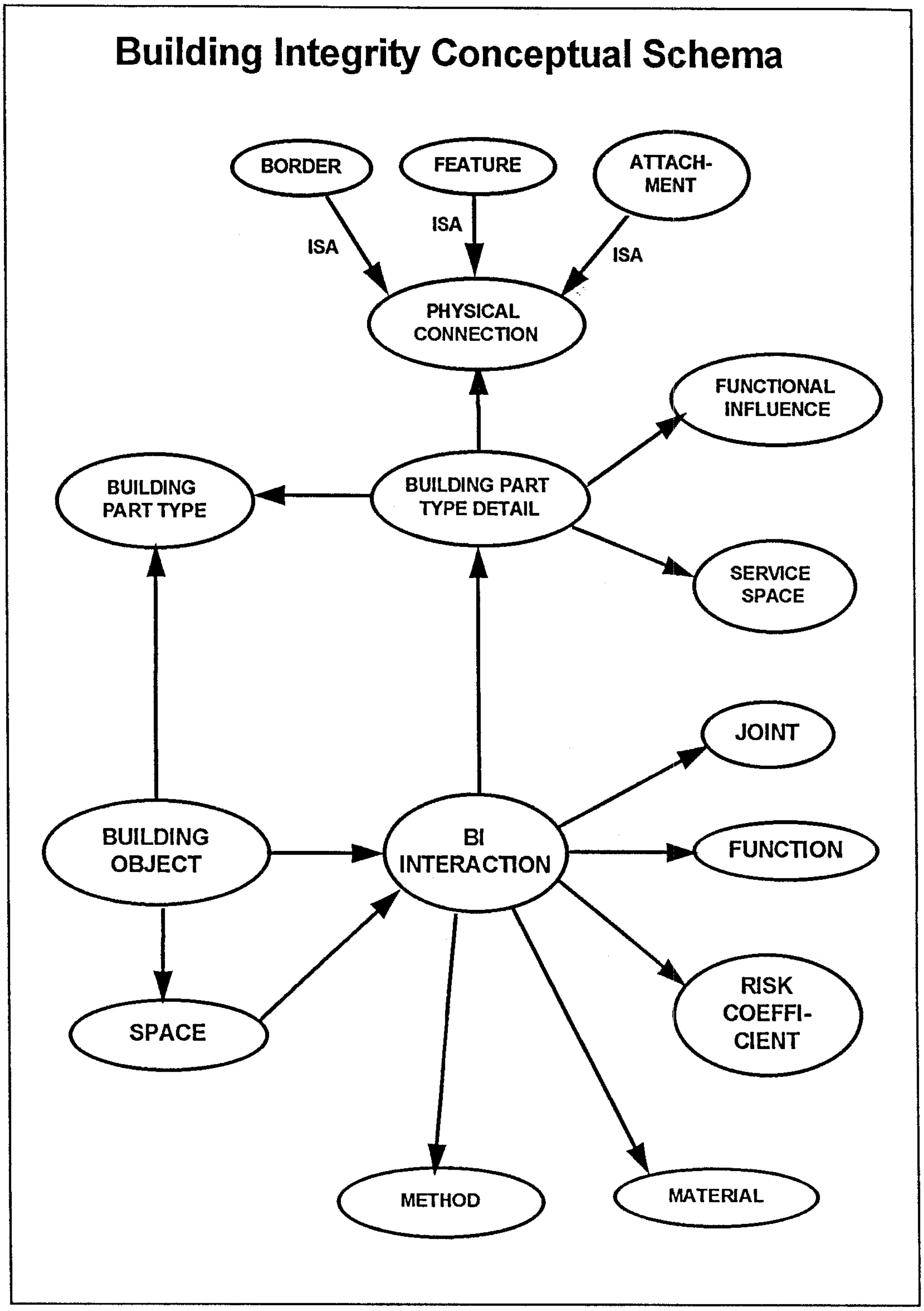


Figure 9. A tentative conceptual schema for building integrity.

6 REFERENCES

ASCE, 1985, *Quality in the constructed project.* Proc from Workshop, Nov. 13-15 1984, American Society of Civil Engineers.

Augustsson R, Hammarlund Y, Jacobsson S, Josephson P-E, 1989, *Kvalitet i byggandet - Kvalitetsfel - Kostnader.* In Swedish, CTH Inst. för byggnadsekonomi och byggorganisation, Rep 21, Göteborg.

Bennett J, Flannagan R, Norman G, 1987, *Capital & Counties Report: Japanese Construction Industry.* Centre for Strategic Studies in Construction, University of Reading.

Bergström S, 1989, *Byggfelsstudier inom SVR.* In Swedish, Väg- och Vattenbyggaren, Stockholm.

Bertfelt O, Dorbell T, Keijer U, Rahm H G, 1992, *Sammanbyggnadsteknik och dess krav på ändamålsenliga strukturer - Förstudie.* In Swedish, Inst. för Byggnadsekonomi och Byggnadsorganisation, TRITA BBO - 26, KTH, Stockholm.

Björk B-C, 1993, *A conceptual model of spaces, space boundaries and enclosing structures.* Automation in construction, Elsevier, pp 193-214.

BRE, 1987, *Building failure patterns and their implications.* The Architects' Journal 5 Feb. 1975, Building Research Establishment, pp 303.

BSAB 9 X, 1993, *Remissdokument för BSAB 9X.* In Swedish, AB Sv. Byggtjänst, Stockholm.

Checkland P, 1986, *Systems Thinking - Systems Practice.* John Wiley, Chichester, 330 pp.

Codd, E F, 1970, *A relation model for large shared data banks.* CACM, 13(6), pp 377-387.

Eastman C, 1993, *Life Cycle Requirements for Building Product Models.* Proceedings of the First Conference on Management of Information Technology for Construction, Aug. 17-20, Singapore, World Scientific & Global Publication Services, pp 369-389.

Finkelstein C, 1989, *An Introduction to Information Engineering. From Strategic Planning to Information Systems.* Addison-Wesley Publishing Company, Sidney.

Freedman D H, 1992, *Is Management Still a Science.* Harward Business Review. Nov.-Dec. 1992, pp 26-38.

Glieck J, 1987, *Chaos.* Abacus, London, 352 pp.

Karstila K, Björk B-C, Hannus M, 1991. *A Conceptual Framework for Design and Construction Information.* CIB W78, Integrated Computer Aided Design, Sept. 16-17 1991, Eindhoven.

Keijer U, 1993, *Building Integrity: Classification beyond Building Part and Spaces.* Proceedings of the First Conference on Management of Information Technology for Construction, Aug. 17-20, Singapore, World Scientific & Global Publication Services, pp 135-147.

Mårtensson Rolf, 1993, *Feleffektanalys (FMEA) för byggbranschen.* In Swedish, SBUF, project number 1101, Malmö.

van Nederveen G A, Tolman F P, 1991, *Modelling Multiple Views on Buildings.* CIB W78, Integrated Computer Aided Design, Sept. 16-17 1991, Eindhoven.

Paulsson B, Appelqvist I, Bengtsson K, Tarandi V, 1990, *Produktionsanpassad mängdavtagning MCAD.* In Swedish, Swedish council for Building Research, Report R14:1990, Stockholm.

Senge P, 1993, *The Fifth Discipline - The Art & Practice of Learning Organisations.* Century Business, London, 413 pp.

Suh N P, 1990, *The Principles of Design.* Oxford University Press, N.Y., 401 pp.

Tarandi V, 1993, *Object oriented communication with NICC.* Proceedings of the First Conference on Management of Information Technology for Construction, Aug. 17-20, Singapore, World Scientific & Global Publication Services, pp 517-527.

Waldrop M M, 1992, *Complexity - The Emerging Science at the Edge of Order and Chaos.* Penguin Books, London, 380 pp.