THE INTELLIGENCE OF INTELLIGENT BUILDINGS

ABSTRACT

The intelligent buildings have been successfully built according to the intelligent building (IB) concepts. They are no scientific definitions of the intelligent buildings, but exact enough to be used for construction purposes. The IB concepts overlap with healthy or green building concepts, or they have much common with the factors of facilities management and integrated facilities management. Lack of a universal definition of the intelligent buildings has encouraged studying the essence of intelligence, knowledge and knowledge management in order to be able to identify what is the intelligence of a building, which makes intelligent buildings different from other buildings.

It has been possible to define the building intelligence as a function of human intelligence. This has been done on the basis of the argumentation which provides answers from the knowledge management theory to the unexpected findings of an empirical survey of the quality differences of two office building types - intelligent and other high quality - carried out in the Helsinki metropolitan area. The derivation of the building intelligence from the human intelligence and the knowledge transformation from the expert knowledge into intelligent properties, as well as the use of the building intelligence by end-users are defined by the Building Intelligence Framework. About these studies has been written a doctor's thesis (Himanen 2003, cf. also Himanen 2004). The forms of building intelligence and some further findings of them will be represented in this paper.

1 INTRODUCTION

Several definitions or rather descriptions of IB concepts exist (Himanen 2003, pp. 55-65). The intelligent building institutes, groups and companies working in building field have been active in defining the intelligent building in practical terms since 1980's, when the boom of intelligent building and smart housing started. Already, the Intelligent Building in Europe Study by DEWG and Technibank (1992) proved the performance of the intelligent office buildings to be effective, and the Intelligent Building Survey (the IB Survey) carried out at VTT in Finland (1994-1997) proved the same fact of a good quality of the intelligent offices (Himanen 2003, pp. 159-194, 205-283.). The IB concepts have worked for advantageous projects (Figure 1.).

2 RESEARCH PROBLEM

Despite several IB concepts, a lack of a universal definition of the intelligent buildings is obvious although for example So (2001) has suggested one in his study of the Intelligent Building Index. Actually So is saying (So & Chan 1999) “that the intelligent buildings are not intelligent by themselves but they can furnish the occupant with more intelligence and enable them to work more efficiently.”

The IB concepts overlap with healthy or green building concepts, or the factors of them have much common with the factors of facilities management and integrated facilities management. The hypothesis of an intelligence of buildings, which differentiates the intelligent buildings from other building concepts, became obvious after the more detailed analysis of two unexpected research results of the IB Survey (Himanen 2004). Those results were:

- On the basis of the all factors of the IB Survey relevant to the equipment the end-users rated the intelligent was with higher grades than the reference buildings. However, the quality difference between the hardware installations – including the building automation and the information and communication technology – could not

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explain the good evaluation of the equipment in the intelligent buildings compared to that in the reference buildings, because the installations of both buildings types were so similar. Did something invisible cause this discrepancy? A phenomenon, called ’a mystery of unspoken technical knowledge’ was found.

The office workers evaluated the glass roofed entrance lobby as important for their work performance, although the time which they spent there during the working day was short especially in comparison to the time they spent in their personal workspace, which was not always evaluated to be particularly good in quality. The question ”Why a rarely used space was evaluated to be profitable?” was called a dilemma of ‘empty’ space.

The IB Survey was carried out in twelve office buildings in Helsinki metropolitan area among 534 office workers in 1994-1995 (Lehto et al. 1997). The primer aim of it was to find out, if the intelligent office buildings are different in quality from other type of office buildings. The core of the study was a questionnaire of 417 variables. It was analysed statistically comparing the two building types: intelligent and other high quality office buildings. The influence of spatial design and the performance of the equipment to the working efficiency of the office workers was the evaluation criterion. The quality difference between the two building types turned out to be true on the behalf of several factors in the favour of the intelligent buildings but in every case (Lehto et al. 1997). Comparison by such classifications of answers as by genders and by working statuses (executives, experts and clerks) was favouring both building types, and that analysis revealed rather the needs to vary the workspace design criteria according to different end-user needs. It seemed that the use of IB concepts counts in many ways, but what was the most important factor making a building intelligent.

3 METHOD

The two above mentioned research problems have been studied by Himanen (2003, 2004, cf. also Himanen & Himanen 2003) on the basis of the empirical data from the IB Survey and the literature available of office space design, intelligent buildings and knowledge workplace. That study has based on more detailed analysis of the data from the questionnaire of the IB Survey and the comparison the results to those of literature (Himanen 2003, pp. 205-283, 348-394, 408-444). In the first place, the intelligent buildings turned out to be statistical significantly better than the reference buildings on the basis of the F-test of the all factors of the IB Survey's questionnaire (Himanen 2003, p. 207.). Further on, the study has based on reasoning or argumentation of the empirical results in the light of the theories on the essence of human intelligence, those of knowledge management and futures studies, as well as systems thinking, quality engineering, engineering economics (Himanen 2003, pp. 115-158.).

4 RESULTS

One can claim that buildings have always been built intelligently. For example, some of the earliest active structures can be found in the mechanism of the Egyptian pyramids stone and sand structures, which are activated by sunbeams, or in the well known idea of the secret passage door opening by pushing a button in a bookcase. The clarification of an intelligent building concept is a process of awakening the conscious mind of long existing unspoken reality of intelligent construction tradition. Data, information and explicit knowledge, but also the tacit knowledge comes a part of our everyday practises and routines by developing the IB concept paradigm. The understanding of the combinations of tacit personal knowledge and the explicit technical know-how are essential for the construction and building industry practices and routines during this post-industrial time as it is in any other sectors of businesses; in working, living, behaving, financing, resourcing, etc.

Each sector of construction is under constant development, which since the 60's has meant increasingly integrating and embedding the information and communication technology (ICT) to existing products, systems and methods. The progress of ICT is universal. However, the digital technology with fuzzy object oriented controls is not the only tool for increasing building intelligence, but all means from mechatronics to biotechnology are used in the intelligent buildings and building component development. At present, it might be difficult to distinguish the sophisticated intelligent building innovations from those of the green or healthy building ones (Lehto 1999b). The holistic multidisciplinary or transdisciplinary approach shows the reference points of the building as Clements-Croome (1999, p. 105) emphasises: “Any consideration of intelligent buildings, whether learning, designing or managing them requires a freedom of thinking which can embrace
trans-disciplinary ideas and systems. The word trans-disciplinary is a truly holistic and highly interactive concept. Intelligent building strategies are dealing with multiple criteria and attempting to integrate ideas over a very wide range.”

4.2 Focus

As mentioned, a dilemma of 'empty' space and the 'mystery of unspoken technical knowledge' have inspired (Chapter 2.) to study the essence of human intelligence and that of building intelligence. It resulted to the derivation of the function between human and building intelligence, which, is mainly based on the reasoning between empirical data from the IB Survey and theoretical knowledge of human intelligence introduced by Gardner (1983 in Dryden & Vos 1996, pp. 120-123.) and knowledge management by Tuomi (1999, p. 100). Nevertheless, the further examination on the knowledge management in the context of knowledge workplace led to the study of the knowledge transformation in the context of design of (intelligent) buildings and the use of intelligence to the satisfaction of occupants' spatial needs in profit making. These approaches ended up to the introduction of the Building Intelligence Framework (BIF) (Himanen 2003, pp. 284-335.), which rely on the knowledge transformation theory of Nonaka and Takeuchi (1995) and that of Nonaka and Konno (1998), as well as, on the Maslow's Hierarchy of Needs (Huiti 1998).

Despite of the close relationship of these two concepts: the Building Intelligence (BI) and the BIF, in this context the focus is in the dependency of the building intelligence on human intelligence and the forms of the BI, as well as in the correlation of the forms of building intelligence and the factors of IB concepts and the BIF will be discussed in more detail in other contexts (cf. e.g. Himanen 2004).

4.3 Factors of the IB concepts

The descriptions of the IB concepts are keyword lists including such factors as follows: end-user orientation, integration, environmental friendliness, flexibility and utilisation of space, movable space elements and equipment, life cycle costing, comfort, convenience, safety and security, working efficiency, image of high technology, culture, construction process and structure, long term flexibility, and marketability, information intensity, interaction, service-orientation, ability of promoting health (therapeutic), adaptability, reliability (stable and accurate), and productivity (profitability) at correctness of basic technical solutions.

4.4 The building intelligence as the function of the human intelligence

There are two typical characteristics of human intelligence, and they are: the tendency of creating artefacts, which also means in modern days the tendency for industrial production, and secondly, the tendency to satisfy one's needs by the tools made by using one's intelligence (Himanen 2003, pp. 128-134). These functional characters of the human intelligence describe also how the human intelligence is used in the building design and property management, and how the end-user of the building benefit from the intelligent building features defined by the IB concepts (cf. Section 4.3.), and which have been used for practical construction purposes in building of IBs (cf. Figure 1.). The BIF gives the theoretical background for these phenomena.

There are several definitions for human intelligence (Dunderfelt 1998, p. 28). Gardner's seven forms of human intelligence and their relation to building intelligence seemed interesting for closer studying (1991 in Dryden & Vos 1996 pp. 345–352, 1983 in Dryden & Vos 1996 pp. 120–123, 1993 in Tuomi 1999 pp. 107–110, 1993 in Dunderfelt 1998 p. 28). They are: musical, linguistic, logic-mathematical, inter- and intra-personal, and visual-spatial, and bodily kinaesthetic (Figure 2. or Figure 3.). Such abilities as to be able to sense the space and motion, to interact with the surrounding and to know the state of the art of the art of one self seemed right away have reflections in the intelligent building technology.
Built environment as well as machinery is man-made. The essence of technology\(^1\) lies in imitation of nature. It can be understood that man makes machinery resembling himself, builds houses resembling him. Intelligent machines and buildings are products of this process. Some think that man-made environment is more human like than resembling other nature. In psychology professor C.G. Jung has made the metaphor between man and the house by talking about the mental growth as a process of building oneself similar to the process of building a house of one’s own.

4.5 The forms of Building Intelligence

The building intelligence can be derived from the human intelligence (Figure 2.). The five forms of Building Intelligence are (Figure 3., the descriptions of the forms cf. Himanen 2003, pp.*, Himanen 2003a, Himanen 2004):

- **Building-connectivity** (speaking and speech recognition including music and linguistics; user-connectivity and control: either personal or automatic or defined by the organisation in concern),
- **Building self-recognition** (building knows the state it is in; a kind of consciousness),
- **Spatiality** (a more conscious understanding of the spatial expression of the architecture, structures, interior design),
- **Building kinaesthetic** (a sense of change, active structures, moveable structures, furniture and equipment, adjustable technology or building services), and
- **Building logic** (embedded sensors to monitor the occupants’ daily activities, combinativity).

Figure 2. The correspondence of the forms of human intelligence and some intelligent building properties.

The role of the intelligence in the context of the buildings has relevance, when the combination can refer to embedding rather than integration of conceptual knowledge of intelligent buildings. It is suggested that the word **combinability** for embedding knowledge or know-how of building intelligence into a building.

Signs, speech recognition, and the semiotics of buildings are referred to as the *linguistic* intelligence. The building properties, such as sounds from an indoor waterfall or background music indicate human *musical* intelligence. Also silence, the opposite of sound or the break of it has to be taken into account. The building senses through stimuli via embedded sensors. Buildings can artificially speak by repeating a tape, or by means of technology that enables speech synthesis. It is hard to consider that any building could communicate for its own sake or, for example, for its own intellectual enjoyment. The building properties as related to human

\(^1\) Technology is defined as (free translation from Nykysuomen sanakirja): "1. procedures, methods used for production, achievement of something; a skill for making or performing; knowledge of means and how to operate which serves a certain purpose... 2. action (manual or industrial), which is based on the knowledge of the nature and the natural laws, the pert of the material culture, which is based on this action".
senses are more about how the building interacts with the facilities management or end-users, and they are included in building-connectivity.

![Building Intelligence Diagram](image)

Figure 3. The forms of Building Intelligence (BI) and the seven forms of human intelligence by Gardner (1991 in Dryden & Vos 1996 pp. 345–352).

### 4.6 The levels of articulation of Building Intelligence

Tuomi (1999, p. 100) has given the levels of the articulation of knowledge (Two left columns of Table 1.). When searching the intelligence of buildings on the basis of the properties of end products, as done in the IB Survey, the level of human knowledge in concern is that of ‘articulated’, because that level means knowledge that is articulated in the product.

<table>
<thead>
<tr>
<th>Level of articulation</th>
<th>Characteristics</th>
<th>Steps of articulation in knowledge transformation in building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tacit</td>
<td>Unorganised and dynamic meaning relations</td>
<td>A part of the human and a part of building intelligence</td>
</tr>
<tr>
<td>Focal</td>
<td>Conscious organized patterns of meaning relations</td>
<td>The intelligent building concepts</td>
</tr>
<tr>
<td>Articulated</td>
<td>Meaning relations sedimented in produced artefacts or expressions</td>
<td>Intelligent buildings</td>
</tr>
<tr>
<td>Verbal</td>
<td>Meaning relations sedimented within a system of concepts</td>
<td>The Building Intelligence and the Building Intelligence Framework</td>
</tr>
<tr>
<td>Socially legitimised</td>
<td>Socially shared conceptual knowledge</td>
<td>Universal definition of intelligent buildings</td>
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</tbody>
</table>

Source: Tuomi 1999, p. 100

On the behalf of the IB concepts the level of articulation of building knowledge is focal - conscious organised patterns of meaning relations, because the definition of the intelligence is missing, but ideas of the meaning of it exists. That is how; 'the mystery of unspoken technical knowledge' makes sense. The office workers could realise the good quality of intelligent working environment despite the fact that the installations in the intelligent buildings were quite the same as in the reference buildings. The good quality was barely based on pure good technology. The design included knowledge, which was not yet on the level of verbal, but the product quality revealed - articulated - the existence of it. It can be hypothesised that such ideas as the user-friendly locations of end-user interfaces of the equipment according to the daily activities of the end-user, or controls serving the end-user purposes, etc. can be practical design solutions derived from the workable IB concepts causing this effect.

Research is the mean for finding out the verbal level of the knowledge of the buildings. The definition of the Building Intelligence (BI) and the Building Intelligence Framework (BIF) by Himanen (2003, pp. 128–141,
445–448) or the Intelligent Building Index (IBI) by So (2001) are attempts to verbalise the knowledge of building. The universal definition will appear after the consensus of one definition is reached, and it is socially legitimised. However, the difference between BI together with BIF and IBI is, that So defined the intelligent building and Himanen the intelligence of buildings. The broadminded content of IBI is related to the factors of the IB concepts. The IB together with BIF are using the theories of human intelligence, knowledge transformation and human needs for finding out the relevance of knowledge of intelligence for the identification of intelligent building from other building concept by the definition of intelligence, not by any other good qualities of buildings.

On the basis of the level of articulation of knowledge it can be realised that before design guidelines, quality specifications, etc. building knowledge has been tacit, which concerns the intelligence of buildings till the 1980's, when the IB concepts started to emerge (Figure 4.). The definition of the intelligent building or the building intelligence makes the use of the concept of intelligence in building explicit. Tacit knowledge will be articulated in various levels among the experts and via the interaction between experts and end-users. Buildings become more intelligent or other forms of building concepts emerge.

Figure 4. The building of intelligent buildings (and smart housing) according to the intelligence of buildings.

4.7 The correlation between the forms of BI and the factors of the IB concepts

The correspondence between factors of the IB concepts and the forms of BI can be found (Table 2.). However, many factors of the IB concepts describe the good practice needed for building any kinds of buildings. Those factors can be classified into two groups:

• The measurements of building intelligence (environmental friendliness, life cycle costing, working efficiency, marketability, image of high technology, construction process and structure, productivity (profitability)) and
• The user-needs, which give the purpose for the intelligent building and define, design criteria of buildings (end-user orientation, convenience and comfort, amenities, service-orientation, ability of promoting health and therapeutic).

There are also other criteria of design and building².

Table 2. The correspondence between factors of the IB concepts and forms of the Building Intelligence

<table>
<thead>
<tr>
<th>Forms of the BI</th>
<th>Factors of IB concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building connectivity</td>
<td>Culture; interaction</td>
</tr>
<tr>
<td>Building self-recognition</td>
<td>Information intensity</td>
</tr>
<tr>
<td>Spatiality</td>
<td></td>
</tr>
<tr>
<td>Building kinaesthetic</td>
<td>Spatial and long term flexibility; movable space elements and equipment; adaptability</td>
</tr>
<tr>
<td>Building logic</td>
<td>Level of integration; reliability (stabile and accurate); correctness of basic technical solutions</td>
</tr>
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² quality standards, availability, accessibility, affordability, design-for-all and technology-for-all principles, sustainability, eco-efficiency, aesthetic, functionality, multi- and trans-disciplinarity, brands, transparency, chaining
5 DISCUSSION

5.2 Making buildings humane

As stated, So (2001) has mentioned that the building itself is not intelligent, but it is providing intelligence, which makes it possible for occupants to perform more efficiently. The idea of the building intelligence based on the human intelligence emerging in the design and building of the buildings, as well as by the feedback of the occupants or their participation in design, justifies the intelligence of the building itself, while the focal knowledge of the IB concepts becomes articulated in the intelligent buildings, that is to say, in the product itself. However, it does not kill off all what So has said, because the building being intelligent itself provides also the intelligence that makes the occupant more effective. Furthermore, the intelligence of a living organism must be distinguished from that of man-made inorganic artefacts. The BI exists on the premise of the human willingness to lend human intelligent via design and production into an article.

5.3 Reasoning behind 'the dilemma of empty space' and 'the mystery of unspoken technical knowledge'

There can be found also explicit hypothetical reasons for the better quality of intelligent equipment than standard office equipment. The performance of the equipment was not tested, but the indoor air quality measurements showed more poor quality in the IBs than in reference buildings (Lehto & Karjalainen 1997), which does not talk for a good performance at least of the control of HVAC plant. Time that was spent working with computers was higher in the intelligent buildings than in reference buildings, and if the device is in use the end-user evaluation is often high (Himanen 2003, p. 359). Differences in rating occur also due to what kind or what type of equipment (Lehto & Himanen 2002). The working status and gender have strong correlation to the quality evaluation of the ICT and building automation (Himanen 2003, pp. 209-215). The co-effects of these factors should be analysed profoundly to answer explicitly to the problem of unspoken technical knowledge.

The poor quality of the personal workspace in the IBs can be due to the small size of them, which results to poor quality evaluations. Also the long working hours spent in personal intelligent working spaces might cause high quality expectations. The high quality total of all spaces in the IBs compared to the other offices result that the small personal workplace with short visits to shared spaces are preferred and the highly evaluated bigger workspaces in the other offices cannot substitute for the lower evaluation of the shared spaces, especially when workers tend to spend their time there, which is the case in the reference buildings.

6 CONCLUSIONS

The idea of an intelligent building can be traced back to the Egyptian times. The IB concepts have worked well in building of intelligent buildings, despite the fact that the IB concepts have been in the level of focal knowledge, because of absence of a universal definition of intelligent buildings, which could have separated the intelligent buildings from other building concepts. The intelligent buildings themselves are on the articulated level of the focal knowledge of IB concepts. Originally tacit knowledge of the idea of an intelligent building has become via focal descriptions articulated in the buildings. The construction activities of the intelligent buildings had made it possible to study the buildings themselves and figure out the intelligence of the buildings in a verbal form. The tacit knowledge of the intelligent buildings has become explicit by the scientific approaches to the definition of the intelligent building and building intelligence, which makes it possible to have more consciously intelligent building process.

On the premise of an explicit definition of intelligent buildings or the intelligence of buildings, it is possible socially to legitimise the universal definition of the intelligent building. In this study, the forms of the building intelligence derived from the forms of human intelligence have been suggested as an option of the universal explicit definition of the intelligence of intelligent buildings, remembering that the knowledge of the building intelligence might or rather will grow in the future, while further knowledge of the human intelligence will emerge.
According to this study the intelligence of buildings has been realised by studying the intelligent features of intelligent buildings and thus the intelligence of intelligent buildings has been found. Because the buildings have been during times products of human intelligence, the building intelligence has emerged in them. There is no need to limit the intelligence of the buildings into the intelligent buildings. The intelligence of buildings has been articulated in various levels of knowledge in buildings of different times.

While building is a product as any other man-made article, also the theory of the intelligence of buildings can be applied into the definition of the intelligence of manufactured products, as well.

8 REFERENCES


