**Decision support to the application of intelligent building technologies**

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**Abstract**

Although considered a current highlight, the concept of intelligent buildings (IB) has not been adopted as quickly and widely as expected. One of the reasons for this is the lack of information and knowledge support to all professionals involved at the design stage of a project. This paper provides a brief overview on the new advances of IB technologies and discusses ways of supplementing the decision making process by adopting two methods for economical and technical aspects of IB applications. It goes on to introduce an on-going research which aims to utilise knowledge based systems to provide comprehensive evaluations to alternatives and decision support to retrofit building projects, when they are being conceptualised.

**Author Keywords:** Intelligent building; Decision making; Knowledge based system; retrofit construction

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**1. Introduction**

Sustainable development and intelligent buildings are becoming one of the current highlights in the construction industry [[7](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib7), [10](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib10) and [5](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib5)]. However, these concepts appear to be more popular with researchers and academics than with building professionals. As new products and technologies are emerging, this problem seems to be more evident as the gap widens between available intelligent building technologies and the actual number of buildings incorporating IB concepts [[6](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib6)].

There are many possible reasons for this gap. One of them is the lack of information and understanding of intelligent buildings among owners and developers of commercial buildings. Developers, with typical least cost mentality, often consider intelligent buildings expensive to build and maintain. They lack true understanding of the IB technology. Very often they are not well informed of the lifecycle costing of the project. As a result, these decision makers often fail to consider the efficiency and flexibility that intelligent buildings can bring to their tenants and users, which will increase lease potential. In addition, as architects and engineers develop new designs of flooring systems and energy saving HVAC components, there are no appropriate channels for the dissemination of these new concepts to would-be users and developers. At the same time, building contractors feel reluctant to take on these concepts in their products fearing that it will make their job more difficult and increase project risk and costs. Again, lack of knowledge and appreciation of intelligent buildings plays an important part.

To rectify this problem, a research project is being undertaken in the Queensland University of Technology, Australia, with an aim to develop a knowledge based system to provide information and decision support to building developers and potential users, on the adoption and application of IB technologies. It involves several major stages of development, such as scope definition of IB applications, categorisation of IB technologies and extraction and formation of decision-making processes of design teams and developers. Unique mechanisms for simulation and knowledge representation developed for the system allow the simulation of decision making models while maintaining system flexibility. The incorporation of life cycle costing analysis into the system adds another dimension and creditability to overall process of the identification, selection, evaluation and feedback for the application of IB technologies.

Having identified some of the possible reasons for the resistance to IB applications and based on these findings, this paper gives a brief review on the recent IB development and its relevance in today’s user requirement. It discusses the specific considerations in the decision making process of IB applications in terms of economical and technical evaluations. Based on these findings, the paper introduces the QUT research project and covers overall research objective, design initiatives, system structure and integration features, and on-going development processes.

**2. Intelligent buildings and their recent development**

**2.1. The significance of intelligent buildings**

Recently significant advances have been made in the design, engineering and construction of “intelligent” buildings, which not only accommodate major advances in office technology but also provide better physical and environmental settings for the occupants.

What is an intelligent building? Although the concept of intelligent buildings is still evolving, it was first brought out in the late seventies when more and more new buildings were equipped with new technologies such as IT [[3](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib3)]. Twenty years later, it is now commonly acknowledged that technologies alone do not make a building intelligent. An intelligent building must also be able to respond to individual, organisational and environmental requirement and to cope with changes. It is also believed that a truly intelligent building should also be able to learn and adjust its performance from its occupancy and the environment [[2](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib2)].

Intelligent buildings are also becoming popular because the demands of building owners and users are changing. While requiring physical space, owners and occupiers of the buildings also require the building to perform [[4](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib4)]. This performance can be measured in many different ways depending on individual concerns but generally fall into the four categories: individual comfort, organisational flexibility, technological adaptability and environmental performance.

For example, the owners should not have to pay a premium for refurbishment every time the tenants in their buildings change. The tenants should be able to make individual adjustment easily with no or minimum cost for things such as office layout, lighting and air distribution. The environment should not suffer from the construction of buildings through their waste or use of hazardous materials. Intelligent buildings meet the new environmental challenge and can respond to each of these concerns.

**2.2. Composition of intelligent buildings**

There are two layers of meanings in an intelligent building, the physical building intelligence and intelligent building management and operation.

**2.2.1. Physical building intelligence**

The lifespan of components in a building varies dramatically as the following list suggests:

Structure

100 (years)

Skin (exterior)

50

Mechanical systems

25

Electrical systems

10

Interior partition

5

Information technology

1–3

Therefore, to cope with environmental, technological and organisational changes, building researchers have devoted much effort to those building components that have shorter lifespan. New innovations and development in flexible façade, energy saving window treatment, automatic lighting controls and relocatable office furniture and fittings are to name just a few.

However, the major asset of an IB lies within its ability to learn and adapt. Hence, the development of new technologies in association with building management and operation is given high priority.

**2.2.2. Building management and operation**

The operation of building and facility management is becoming much more business driven and managers will increasingly see occupants of buildings as customers or clients who must be kept happy rather than tenants who just happen to occupy the buildings. To provide a better service, managers must be able to utilise both human systems for facility management and computer systems for building and office automation. In turn, this demands three levels of solutions to ensure a successful intelligent building in place. First, an effective building shell is needed to absorb information technology expansion and allow organisations’ growth and change. Second, building and office automation and space management systems are required to facilitate effective internal and external communication, support environmental and individual comfort control and monitor change, access and usage. Third, there is a need for integrated technologies and services that allow the integration of disparate organisations, systems, data and personnel to focus on the common goal of increased business effectiveness.

**3. Specific considerations in the implementation of intelligent building technologies**

It was discussed earlier that the application of new IB technologies was met with problems associated with the decision making process, in the conception stage of the project development. Key issues include the lack of information and established assessment criteria. To provide evaluation and feedback on the performance of intelligent buildings with respect to conventional building projects, two methods of evaluation can be used together with an analysis of design and construction options. As discussed below, the first associates Life Cycle Costing (LCC) analysis to evaluate the economical benefits, and the second uses MSI index (Magnitude of System Integration) to measure the level of integration among building systems.

**3.1. Economical aspects**

The LCC analysis is a method used to assess design alternatives considering all the significant costs of ownership. The ultimate objective of LCC is the determination of optimum design decisions following the evaluation of all viable design alternatives. The LCC process can be applied to a total building or to any building components. It generally includes the following steps [[9](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib9)]:

• Choose design alternatives for cost studies.

• Determine elements for each option to be studied.

• Establish capital cost and cost-in-use for each alternative.

• Convert cash flow for each option to a common time basis for rational comparison using discounting techniques.

• Select final design solution with consideration of function, quality etc.

For a typical office building project, the components considered in LCC are listed in [Fig. 1](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634#fig1). Single building systems apply those LCC components related to capital cost, maintenance cost, operating cost and demolition cost.

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| [Full-size image (9K) - Opens new window](http://www.sciencedirect.com/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6V4S-411W3CG-B&_image=fig1&_ba=1&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=full&_orig=search&_cdi=5766&_issn=09601481&_pii=S0960148100000859&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=8fe3a5d5ee43a8bdd159fcef676a2b76) | [Full-size image](http://www.sciencedirect.com/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6V4S-411W3CG-B&_image=fig1&_ba=1&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=full&_orig=search&_cdi=5766&_issn=09601481&_pii=S0960148100000859&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=8fe3a5d5ee43a8bdd159fcef676a2b76) (9K) |

Fig. 1. LCC cost components for an office building [[9](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634#bib9)].

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In addition to cost components, another critical aspect of LCC is the determination of evaluation period over which the building or component is expected to operate. For the purpose of evaluation, the following operation periods are suggested [[8](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib8)]:

• The shell, skin, and structure are designed to last for at least 50 years.

• The services, the primary mechanical and electrical systems have a lifespan of usually no more than 15 years.

• Ceilings, partitions, furniture and finishes, which constitute the fitting-out to accommodate a particular division or tenant, are often cleared away within five to seven years.

**3.2. Technical aspects**

Building intelligence also relies on the integration among the various service systems and between these systems and the building structure. In order to assess the degree of systems integration, Arkin and Paciuk [[1](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib1)] proposed a simple index (MSIR) to evaluate and compare systems’ integration in some existing buildings.

Image

where

MSI

Magnitude of system integration

MSIR

Normalised index for measuring the integration of service systems in a building

NS

Number of available service systems in a building

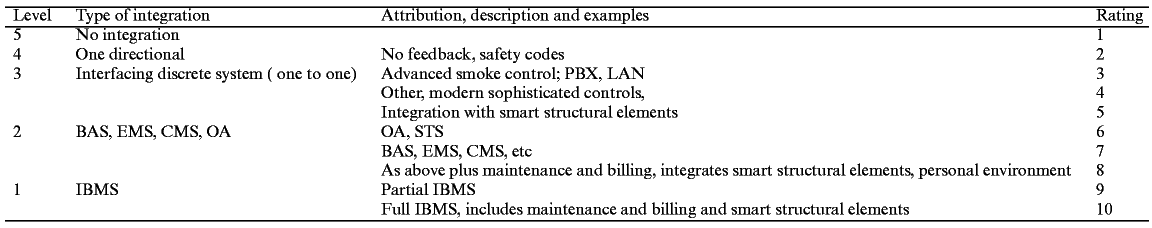
R

Rating attributed to the integration feature of service systems

(refer to [Table 1](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634#tbl1))

By contemplating design options involving these building systems and service systems, the magnitude of system integration can be calculated to provide comparisons between alternatives within a degree of confidence.

Table 1. Examples of scale for systems’ integration in intelligent building[a](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634#tblfn1)



[Full-size table](http://www.sciencedirect.com/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6V4S-411W3CG-B&_image=tbl1&_ba=&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=full&_orig=search&_cdi=5766&_issn=09601481&_pii=S0960148100000859&view=c&_isTablePopup=Y&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=cd08c3bc6829746a8f71b2cade15e0de) (11K)

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**4. The research in decision support for intelligent buildings at QUT**

**4.1. Research objective and orientation**

The research project being developed at QUT aims to fill in the gap between increasing interests and demands on intelligent building applications and the lack of information and decision support at the conception stage of office building development.

Following an extensive literature review, it was decided that the proposed system development must incorporate three key features:

• Ability to conduct consultation processes of IB decision making during project conception and design.

• Ability to perform basic life cycle cost information and to provide comparisons.

• Ability to assess the level of building intelligence based on user options and indicate areas of concerns and possible improvement.

• Ability to present alternatives to users, provide evaluations and make recommendations of decisions.

With the novice nature and vast body of knowledge to be accessed in these type of projects, it has been decided that a prototype system should be developed in a controlled domain of intelligent building applications. At the same time, this area of application must also be practical so that the research results can be readily verified and used by the industry. The authors have conducted several interviews and mini case studies among clients and building contractors in north-eastern region of the USA and in South-east Queensland in Australia. With the support from three organisations, it was decided that the research uses its limited time and resources on the study of retrofit projects of office buildings, an area which has been a recent highlight among major corporate building landlords in the USA and in Australia.

**4.2. The use of knowledge based systems**

A Knowledge Based System (KBS) provides a way to solve complex decision-making problems by extracting the underlying logic of the implicit knowledge and expressing it explicitly in the form of a structured model. Therefore, it is particularly suited to processes of selection, evaluation and comparisons for intelligent building technologies.

During the last decade, many KBS were developed in the building and construction industry. Examples include: strategic planning of construction project, construction schedule analysis, building defect diagnosis, etc. The most frequently used techniques for developing KBS are rules-based systems, case-based systems, model-based system, artificial neural networks and genetic algorithms, applicable to many different kinds of decision-making scenarios [[11](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V4S-411W3CG-B&_user=6533825&_coverDate=03%2F31%2F2001&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000027478&_version=1&_urlVersion=0&_userid=6533825&md5=1390e17a01600930a8242ae2ddd3f634" \l "bib11)]. Since reasoning criteria, life cycle costing and MSIR index method are well defined, it is favourable for the research to adopt the rule-based technique to develop the KBS, which consists of a knowledge base, an inference engine, a context memory and a user interface.

Specific effort is being made to ensure that the knowledge of intelligent building evaluation and analysis can be broken into core knowledge and ancillary knowledge, so that they are stored in different structures in the system. The benefit of this is the flexibility of user control and ability of user facilitated update to parts of the knowledge base, so that each user’s individual problems can be reflected and the entire system can be kept up to date.

**4.3. Knowledge identification and extraction**

For the research reported here, the retrofit project scenario is directly associated with the use of raised floor technology coupled with flexible HVAC, data and voice distribution and the use of re-configurable and relocatable office fittings and furniture. The use of day lighting, task lighting, task air distribution and modular power/data connectors are also included in the analysis.

The knowledge and procedures of retrofit office building project has been broken down into:

Stage 1: Definition

• Project briefing

• Existing physical conditions

Stage 2: Floor

• Strip and clean

• Raised floor structure

• Floor covering and treatment

Stage 3: Underfloor distribution

• HVAC distribution

• Power/data distribution

Stage 4: Finish

• Lighting

• Interior configuration

• Office fit-out

**4.4. System design and features**

The new IB decision support system carries a design philosophy that provides maximum information in a decision making process while maintaining flexibility to suit different users. All of this is achieved in a consultation format facilitated by the main system and two ancillary systems.

The main system attempts to guide users through the building conceptual design process which is carried forward chronologically through the four stages listed above. As users following through particular paths of alternatives, two ancillary systems incorporating LCC and MSIR evaluations will record these options and accumulate relevant data. At the end of each stage, users will be able to view a summary of design alternatives to date in conjuction with LCC and MSIR values and finalise suitable options accordingly. For example, electrical equipment can be highlighted when systematic consultation reaches building electrical system design stage. Once the building design process is completed and all the design items determined, the program will produce an estimated cost and an MSIR index for the entire building, together with a summary of this particular IB design.

**4.5. Processes of development**

The research project is going through a six-stage development with status indicated as follows:

• Literature review and evaluation of past retrofit projects — 100% completed

• Knowledge elicitation on IB facilitated retrofit project — 60% completed

• Methodology development for knowledge storage and data retrieval — 50% completed

• Decision model establishment — to commence

• KBS system structure development — to commence

• Test runs and debugging — to commence

As a three-year project, the research still has much work remaining before the decision support system can be functional. The next stages of work include confirmation of knowledge storage and retrieval, characterising the decision making processes, conceptualisation of the system structure and features, and the integration between the inference mechanism and knowledge based systems.

A series of test runs will be combined with verification and evaluation of the system by building clients and design managers in contractors. Time was also allocated for debugging and revisions.

**5. Conclusion**

Intelligent buildings are set to play a major part in the future office building development. This has been demonstrated by the changing business requirement and the subsequent adoption of intelligent buildings by major corporate clients as building users/tenants such as, IBM and JP Morgan. However, the application of IB technologies is lagging behind their invention and development. There has been inadequate support to the dissemination of information and particularly the decision support at the conceptual design stage of building development. The objective of the paper is to raise awareness of the importance of maintaining a comprehensive understanding of IB technologies, keeping up to date with emerging alternatives and being informed of the whole picture (financial/technical/organisational) of IB implementations. The on-going system development introduced here attempts to fill in the gap between increasing demand and the lack of tools in tackling the complex issues of selecting the most appropriate design alternatives, when clients and consultants work with other construction professionals for IB applications.

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