

The Role of Technology in Sustainable Architecture

What is “Smart”?

In a technological context, “smart” systems use Information and Communication Technology (ICT) to optimize their performance by adapting to changing conditions in a dynamic environment. The embedded artificial intelligence of such systems is essentially a crude imitation of human intelligence, which allows the system to make the necessary “decisions.” Following on from this, a “smart building” is often understood to be a building, in which optimized performance—usually measured in energy, sustainability and economic terms—is achieved with the help of an integrated physical and digital infrastructure. In these buildings, ICT systems enable the collection, processing and production of information, which is utilized to enable an ongoing optimization process with the aim of achieving enhanced operational performance. Similarly, a “smart city” is often understood to be a city, in which ICT systems are employed extensively to help achieve improved performance.

“Smart,” used as an adjective to describe a person, implies properties associated with intelligence and good judgment. An alternative interpretation of smart buildings and cities, to the one outlined above, could be one in which “smart buildings” and “smart cities” are understood to be buildings and cities that, through intelligent design, provide spaces with optimal conditions for human well being in its widest sense while using minimum non-renewable resources. In this case, the adjective “smart” is justified by the optimized performance, and the intelligence is that of the designers, whose intellectual efforts enable the enhanced system performance of these entities. “Smart” technology in the form of simulation software is increasingly used in the design of buildings and cities with the aim of producing a built environment which achieves a high energy and environmental performance with a lesser need for technical systems and a lower energy demand during building operation. In extreme cases, the use of technology during design can eliminate the need for whole technical systems in the completed building.

When is a Building “Smart”?

How can we recognize a “smart building?” Certainly the attainment of a high building performance would seem to be a prerequisite condition. After all, a building with a suboptimal performance can hardly be called smart; in an energy context, the relevant performance is the energy efficiency or building energy performance. Now, unfortunately the term “energy efficiency” in the building sector is often misunderstood and low energy consumption is often falsely equated with high energy efficiency. Improving energy performance is thereby confused with a mere reduction in energy consumption. In order to properly evaluate performance however, we must consider the benefits and qualities obtained from the energy “consumed.” In the context of the thermal performance of buildings, energy efficiency can be understood to be the relationship between the quality of the internal thermal environment and the quantity of the energy used to maintain this. High energy efficiency is achieved by minimizing energy demand while simultaneously achieving optimal internal comfort conditions in the spaces of the building. Energy efficiency is, simply put, the relationship between output (benefit) and input (resources).

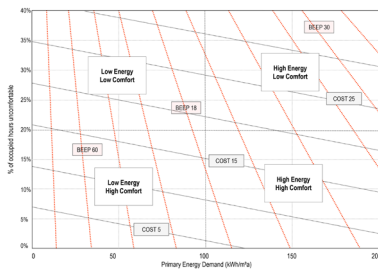


Fig. 1 BEEP method for evaluating true building energy performance

Unfortunately, the legal instruments currently employed to regulate the achievement of energy efficiency of buildings deal solely with energy demand or consumption and not with energy efficiency. In the context of a research project, the BEEP (Building Energy and Environmental Performance) method developed at the Institute for Buildings and Energy at Graz University of Technology is the first evaluation method which allows the true energy efficiency or energy performance of a building to be determined and thus compared with alternative design options or with other buildings (fig. 1). The BEEP method, which quantifies the relationship between the quality of the internal thermal environmental conditions and the quantity of primary energy required to achieve and maintain these, offers significant advantages when compared to the other methods used to date, as it also allows the physical limitations of the building envelope, construction and HVAC systems to be taken into account. The evaluated energy performance (BEEP Value) has the physically meaningful units of comfortable hours per kWh/m²a (kilowatt hour per square meter and year) primary energy demand.

How we as a society measure, evaluate, reward and punish the various strategies and concepts employed to achieve energy performance will strongly influence the future development of architecture. The development of methods for the evaluation of energy efficiency in the area of the built environment is therefore an important and thus far fatally underestimated factor in the future development of the architectural discipline. Results of case studies examined using the BEEP method have clearly shown that low energy consumption cannot be equated with high energy efficiency and that the use of a sophisticated evaluation method such as BEEP in

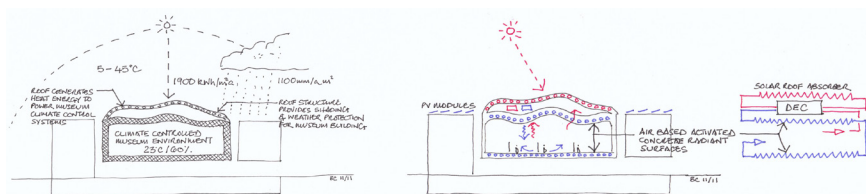
place of the methods currently in use would inevitably lead to a radically different future development of architectural design. Above and beyond this, energy efficient architecture must be understood as a triad comprising minimized energy consumption, optimal internal conditions, and excellent architectural quality. It is possible, with the BEEP method, to combine the first two parameters and objectively determine the best combination. The third parameter should also be evaluated; in recent years, this aspect has suffered in the name of energy conscious building. This is a development that our society cannot afford. Sustainable development cannot by definition proceed with a simultaneous loss in the architectural quality of our built environment.

“Smart” Energy Design

The “Energy Design” of a building comprises the development of strategies and concepts to capture and utilize the transient energy flows in the building’s external environment in order to create optimal internal environmental conditions in the building spaces and to generate renewable energy for use in the building and/or for export to the surrounding urban infrastructure. The overarching goals are to maximize building energy performance and create buildings which are capable of meeting the challenges of the future.

A building is designed to exist in a natural environment with continuously changing conditions (temperature, humidity, air movement, light, sound etc.) and provide the desired and more or less constant internal environmental conditions within. Two approaches can be followed to achieve this goal; the conventional twentieth-century approach of sealing off the external environment as much as possible and employing mechanical systems to provide the desired internal conditions; or the alternative approach of deploying building form, construction and skin to capture and utilize the natural external environmental flows to allow the creation of the desired internal conditions. An example of the second approach, in which — similar to the strategies employed in Asian martial arts—the energy of the “attacking” forces are captured and utilized to achieve the desired result, is provided by the competition entry for the Patna Museum in India (Architect: Coop Himmelb(l)au), for which a solar-powered cooling system was developed (fig. 2). The external skin of a double skin concrete roof including a selective coating is utilized to capture solar heat energy which is transported away by integrated air ducts and used to power the building’s cooling system, which includes dehumidification of the air using a silica gel coated wheel. In a second system, the treated air flows through embedded ducts within the inner concrete construction to activate the exposed thermal mass before entering the space.

Fig. 2 Energy concept for the Patna Museum in India (Architect: Coop Himmelb(l)au)



It goes without saying, that the design of buildings such as these is complex and requires more effort than the conventional design approach. Allowing external forces to infiltrate the building in a controlled manner requires a more sophisticated approach. Nevertheless the approach of working with instead of against natural forces is, without a doubt, the future of sustainable building design. The Energy Design of buildings in practice is a design process similar to the architectural design process, in which invisible energy flows inside and outside the proposed building are manipulated to achieve the design goal of an optimal internal environment. In place of the deployment of standard solutions and the piecing together and arrangement of standard components in specific configurations of mechanical building systems, Energy Design applies the scientific principles of thermodynamics, heat transfer, and fluid mechanics to develop solutions which achieve these aims through the use of multi-functional building elements, which simultaneously take on spatial, functional, and energetic functions. The discipline of Energy Design requires a synthesis of creative design talent and precise analytical skills. Dynamic simulations are used to assess and verify the feasibility of the proposed concepts and to optimize and validate the design solutions. Thus, the use of “smart” technology allows an ongoing optimization process to help achieve the desired performance.

“Smart” Skins

The building envelope is of particular importance in the design of an energy efficient building. Alongside active energy production, the building’s skin should act as an adaptable filter between external and internal environmental conditions. On a current project, we are developing movable elements, which, when in a closed position, form an air-tight connection with the primary building façade and thus allow the transparent proportion of the building skin to vary, down to 0% if the spaces behind the façade are not in use or if the use of the spaces at a given time does not require daylight. Such a variable building skin can react and adapt to both internal and external conditions providing “Space on Demand”. Smart materials, which can change their physical and/or chemical characteristics in order to accomplish the desired adaption to changing conditions, are a further possibility currently being studied.

For the Braun Headquarters Building in Kronberg, Germany, completed and in operation since 2000, a high-performance double skin facade was developed, which was provided with complete automatic control (fig. 3).

The porosity of the skin is varied according to external conditions. The solar control blinds in the façade cavity are automatically adjusted depending on the degree of incident solar radiation. Artificial lighting is also automatically adjusted depending on external light intensity. The offices are naturally ventilated via manually operated narrow opaque ventilation elements (fig. 4). This concept not only reduced building energy consumption and offered improved comfort for the building’s users but also proved the economical feasibility of double skin façades in certain conditions. The effectiveness of the high–performance double–skin façade allowed complete building systems, in this case the conventional heating system and the mechanical ventilation of the external offices, to be disposed of, and thus led to considerable capital cost savings on the buildings mechanical services. A network of capillary tubing integrated into a thin plaster layer on the underside of the concrete slab, fed with warm water in cold weather and cool water in warm weather, is the only system needed to provide comfortable internal conditions in the offices. The fact, that a modern transparent office building can be optimally conditioned with such a simple system is attributable to the energy performance of the building skin.

When is a City “Smart”?

Does a “smart city” have to consist of “smart buildings?” And if it does, does that entitle the city to be regarded as a “smart city?” If we are willing to accept the arguments above, obviously not. A city that is not achieving a high performance can hardly be called smart. The performance of a city depends on the performance of the many subsystems that comprise the whole city system. The city must be understood as a system, as an interconnected set of elements organized in a structural pattern and producing a characteristic set of behaviors. In the research project, “City of the Future,” we are studying hypothetical models for a future city with strategies based on spatial and temporal densification and decentralized energy production alongside urban farming. One key factor in these considerations is urban density, and we are currently working on studies to determine the optimal degree of density from an energy perspective. The measurement of what we call, “real density,” in future cities will need to incorporate the large areas of land required to generate renewable energy and the incorporation of these areas into the external surface area of building structures will in turn influence the determination of the optimal density.

Our research shows also that achieving real progress in sustainable development will entail the radical restructuring of the physical infrastructure of society. Alongside spatial densification, strategies for temporal and digital densification need to be considered. Work on a research project concerned with the nature of the relationship between different forms of teleworking and the total energy efficiency in society provided new insights (fig. 5). In recent years the use of new forms of working has unquestionably

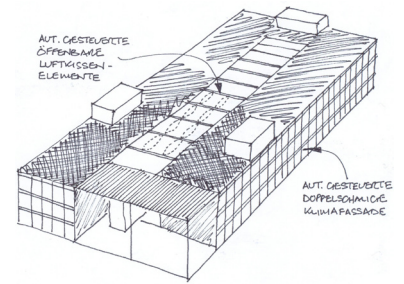


Fig. 3 Building envelope concept for the Braun HQ building in Kronberg, Germany (Architect: Schneider + Schumacher)

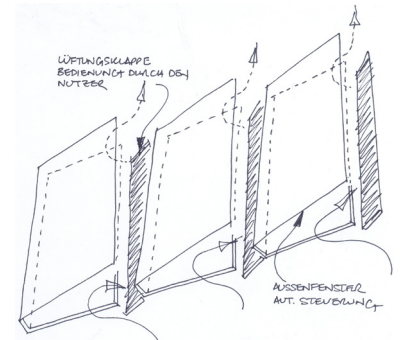
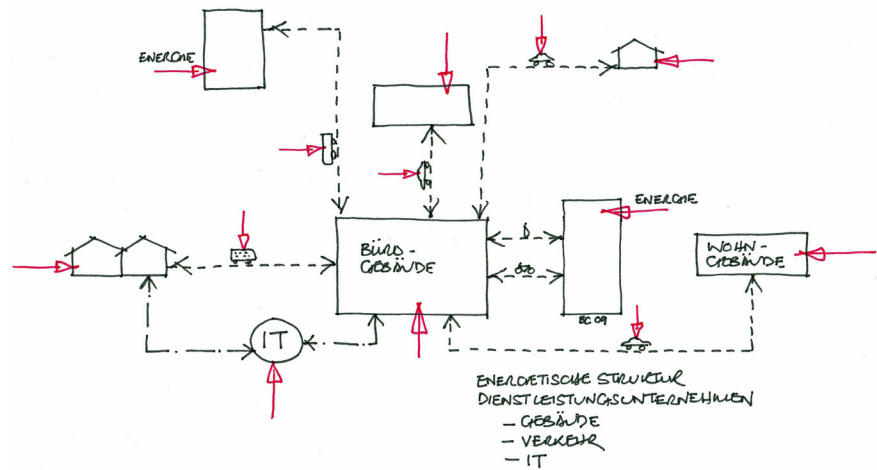


Fig. 4 Double facade concept for the Braun HQ building in Kronberg, Germany (Architect: Schneider + Schumacher)

increased energy consumption. There is a potential however to use these new parameters to generate radically new forms of building and transport systems with the aim of increasing total energy efficiency. To study this, we modeled the energetic structures of typical corporation and company structures. A central issue was the effective use of space and time and in the course of the project we derived a new unit to measure the degree of utilization of our building stock: m^3h (cubic meters and hour), the product of space and time. The research results show that the implementation of various teleworking models can reduce the total energy consumption of a typical company structure by about 25%.

Fig. 5 Research project “The potential of Teleworking to increase energy efficiency of cities”



In this research, particular focus was placed on the utilization of synergies between physical and virtual infrastructure, living and working spaces, and teleworking, among others. In the search for strategies for spatial, temporal, and digital densification, new typologies for vertical structures incorporating all the necessary infrastructural elements of society—including even industry and agriculture, food production, and energy generation—were developed. These so-called, “Hyper Buildings,” function like individual cells in a city model organism. In this cell structure, each cell has the ability to work independently and function in a self-sufficient manner. However, when linked together, they mutually assist each other so that the whole is more than the sum of the parts. The Hyper Building itself is a structure which allows a population density roughly equal to that of Manhattan, needs no external energy supply, no external water supply, produces no waste, emits no CO₂ and needs little or no external food supply. Space for residential, office and industrial use are provided alongside parks and areas for agricultural, biomass and energy production. Linked together they form a 3D-city structure, radically improving the quality of life compared with cities of today and offering urbanity, nature, density and diversity (fig. 6). Central to the concept is the synergetic integration of the various systems and the use of symbiotic relationships between nature, man and technology. The urban design of cities needs to be conceived of in more spatial and three dimensional terms than has been the case up until now. Circulation, mobility systems, and public spaces need not remain



Fig. 6 Research project “Hyper Building City”

trapped on the ground plane. Various layers at different vertical levels are conceivable in a truly three dimensional spatial arrangement of public and private life. The obtainment of optimal density can lead to totally new qualities in urban life and these considerations are not limited to the design of new cities in rapidly developing countries such as China and India. With the knowledge that, in the course of the next fifty years, existing city structures will drastically change on account of continual improvements and renovations, it is imperative to develop a masterplan for all of our cities now, new and old, together with a vision of the city in fifty years time. Why? Because every intervention we make between now and then, every new building, every renovated old building is a fragment of the “City of the Future.”

High Tech or Low Tech

A recurring question in recent times, and one which we have just started to examine in research, is the question “High Tech” or “Low Tech.” Which approach is more suited to help achieve a sustainable development of architecture and urban design? A substantiated discourse on this question has not yet been established in the scientific community and discussions in architectural circles seem to be limited to purely stylistic concerns. On the other hand, a certain tendency towards a preference for a low-tech approach can be discerned amongst many architects in practice and in research, and also amongst students of architecture. This leaning towards low-tech would however seem more grounded on an emotional than intellectual level. This development is somehow fascinating and, at the same time, somewhat disconcerting for a society which depends so much on technology in everyday life. One could of course conjecture, that it is precisely this dependence which fuels the current seduction with “Low-Tech.”

Why is low-tech architecture “in?” Is it marketing hype for a “new style?” Is it because the approach seems to match the stylistic language of certain architectural goals? No one seems to want a low tech mobile phone, a low tech car, or a low tech computer. Why then a low tech building? And when is something “high-tech?” This question is not as easy to answer as it might appear. To have a meaningful discussion about the merits of a high-tech or low-tech approach respectively, we need to first arrive at a definition—or at least a loose understanding—of what is meant by these terms. We are currently working on developing a methodology to enable us to determine whether a building should be classified as high-tech or low-tech depending on the amount and degree of sophistication of the technologies employed in the building.

Imagine a low-tech building made of natural materials, simple and affordable, which uses natural forces in a passive way to provide a stable comfortable environment. A building which requires little maintenance

and which needs user interaction to function, thus supporting the development of a “relationship” between the occupants and their building but also between them and the external environment. And now imagine a high-tech building, which “lives,” which “thinks,” which “learns” and knows what its occupants desire and how best to achieve this, which interacts actively with its environment, which provides maximum comfort levels, uses minimum resources to achieve this and on top of this, supplies the surrounding infrastructure with energy and water. A building, which uses the latest technological advances to reduce embodied energy and increase recyclability. Designed according to biological principles, a building, in which the skin, the respiratory and nervous systems work together, combining natural forces and technology, functioning automatically but allowing user interaction.

Which building would you like to live in? Which building would you like to work in? Which buildings should we be designing? Is it our responsibility to use the latest technology to achieve the highest overall performance? It could be that your answer to these questions is not the same in every case. A further question of interest is, whether a high-tech approach can be used to reduce mass, material and land use due to buildings. A fundamental question is: which approach is more compatible with a sustainable future development. When we analyze case studies during the search for answers to these questions, we are less concerned with the appearance of the building as a parameter in determining whether a building is high or low-tech and more in the substance of the approach.

Smart Use of Smart Technology

Experience with real buildings has shown how important it is to place people at the center of our considerations relating to the issues outlined above. People, not buildings, are ultimately the users of energy. The respective cultural context, in which a given building is located, is also of major significance. Examples such as so-called passive houses in Austria, which were designed without a “tactile” heating source in the spaces such as a fireplace or a radiator or the use of so-called silent cooling systems, such as chilled ceilings, commonly utilized in Central Europe, in parts of the world, where air conditioning systems provide proof of their existence and functionality by virtue of the associated noise, air movement etc. have shown that despite perfect technical functionality, a chosen system may not be fully accepted by its users due to culturally dependent user expectations. It is therefore important that designers gather knowledge of relevant user expectations within a certain cultural context and take these into consideration during design, as these vary considerably throughout the various regions of the world. Experience shows, that it is possible to change user expectations, if this is desired or deemed to be necessary. However in the majority of cases, such a process requires substantial time and effort.

All this however, is not meant to suggest in any way that technology is not needed to achieve optimization of building energy performance. Alongside applied technologies in facade and HVAC systems such as those discussed above, technology can play a useful role in providing feedback. This can occur at two levels. On the one hand, feedback loops can be provided in a technical building management system. Necessary adaptations may be carried out automatically or human decision making and action on the part of a building operator may be requested. Feedback can however also be directed to building users, allowing them to make better decisions and thus contribute to improved building performance. In fact, sometimes the possession of such knowledge can lead to an increase in a building user's subjective perception of the comfort level, enabling reduced energy consumption without the need for any further action. Experience shows that people are willing to accept a wider range of environmental conditions, if they are allowed to exert some influence on the climate control mechanisms employed to provide the environmental conditions in which they find themselves. Building systems should therefore in most cases enable such influence, e.g. by providing the possibility to override solar shading, natural ventilation, HVAC systems, etc. Technology can be employed to ensure that the total building performance is maximized. Buildings can be seen as living organisms and designed along these lines. Not a "machine for living," as proposed by Le Corbusier in *Vers une Architecture*, in which it was assumed that all people had more or less the same needs, which were to be met automatically by the building and its systems, but rather an integrated, intelligent, sensitive, sentient and adaptive "living machine," which supports the individual life and needs of its occupants.

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