Title: **Thinking Out of the Box – Advanced Façade Design and Technology**

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Subjects: Architectural/Design
Building Materials/Products
Façade Design
IT/Computer Science/Software

Keywords: Façade
Parametric Design
Prefabrication
Technology

Publication Date: 2015

Original Publication: Global Interchanges: Resurgence of the Skyscraper City

Paper Type:
1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Thinking Out of the Box – Advanced Façade Design and Technology

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Working for the façade construction company Gartner, he was responsible for high-rise projects such as the Jin Mao Building, Shanghai. He joined Schueco in 1998, first as Technical Director, later as Senior Vice President Engineering (projects e.g. Al-Tijaria Tower, Kuwait). Since 2014 he is Head of Corporate Building Excellence and technical ambassador for Schueco worldwide.

Abstract

The thinking out of the box approach for advanced façade design and technology takes into consideration form and function of the façade as well as aspects of production, installation, maintenance and demolition. Modularly designed façades - with scalable functional groups having optimized interfaces and standardized functional principles - can be planned and executed efficiently and with a high quality. The introduction of cyber-physical systems (CPS) into the façade business will comprise smart machines, storage systems, production facilities and building site terminals capable of autonomously exchanging information, triggering actions and controlling each other independently. Our future will be based on the continuous digitalization of the process chain, connecting architects and engineers as well as main contractors, system suppliers, façade and maintenance companies with their specific activities spread all over the world. This will radically transform the competence profiles of all involved parties.

Keywords: Adaptive facades; Parametric Design; Prefabrication

Within the past 250 years the world faced three waves of industrialization. All of them gave birth to a number of innovations, especially new technologies and new architectural design that seemed to be unpredictable. The First Industrial Revolution transformed human life by changing methods of manufacturing, the way people made a living, and the products available to them. The Crystal Palace (London 1851) often cited as the birth of the façade has been effecting architecture in the modern world. A changed societal structure required new types of buildings unimagined in a previous age. With the firm conviction, that great ideas do not pop fully formed out of brilliant minds, Thomas Edison broke the myth of the lone genius inventor by creating a team-based approach to innovation in the late 19th century. It was an early example of what we nowadays call "design thinking" (Plattner, Meinel & Leifer, 2008), a human-centered methodology that is powered by a thorough understanding of what people want and need in their lives and what they like or dislike. During the 20th century, with globalization progressing apace, local traditions increasingly took a back seat. In the late 1980s it became of more significance that façades don't just have to "look good". Daniels pointed out that they are the key for indoor comfort and operational expenditures (Daniels, 1995). In the new millennium social systems, living arrangements and working patterns have changed faster and more radically than ever before. The unstoppable desire of people to live comfortably takes a heavy toll on the environment. The well-documented climate change has mutated to a global challenge. There is a pressing need for a global paradigm shift. Sustainable building design takes into account the local environmental, economic and social aspects.

Innovating Out of the Box

Innovation is a principal source of differentiation and competitive advantage. Generally, there are two common strategies in innovation-management, the technology push and the market pull strategy. In the technology push strategy the stimulus for new solutions comes from research. Within the market pull strategy the innovations' source is a currently inadequate satisfaction of customer needs. The basis for the technology push innovation-strategy is to identify technological trends. By now the introduction of the "Internet of Things and Services" into the manufacturing environment is ushering into the fourth industrial revolution - named "Industry 4.0" which holds huge innovation-potential. Smart (off- or on-site) factories allow individual customer requirements to be met and mean that even one-off items can be manufactured profitably. Industry 4.0 will have a significant influence on the architecture of the 21st century in exactly the same way as series production shaped the architecture of the 20th century (see Figure 1).

Within the market pull innovation-strategy anticipating the customer's needs is an important aspect. Assuming, that the future will not be a straight-line graph of current trends carried into the future,

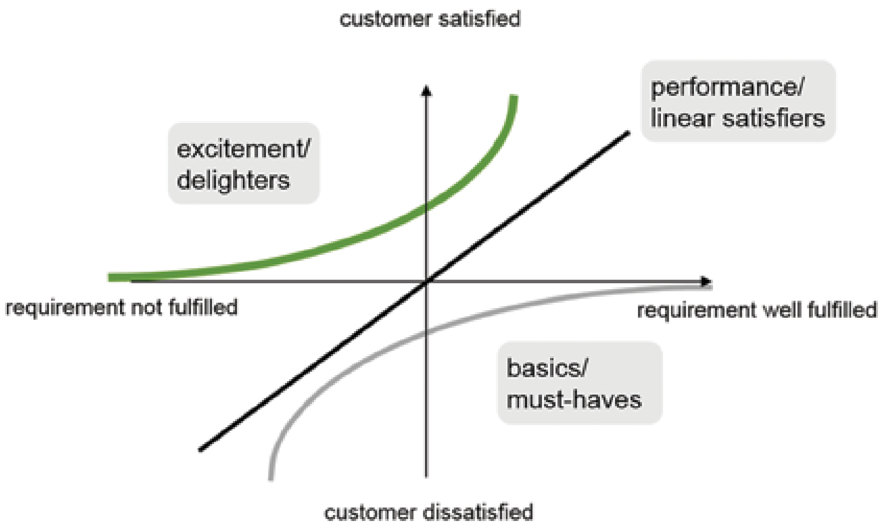

Figure 2. Factors for satisfaction of customer needs (Kano,1984). (Source: Schueco International KG)

the method of scenario thinking creates more probable "futures". Scenarios thinking starts by dividing our knowledge into two domains:

- Things we believe we know something about (such as demographics and mineral reserves)
- Elements we consider uncertain or unknowable (such as social, technical, economic and environmental aspects).

The combination of the two domains within scenarios is a good basis to find out, how the customers` current needs will be influenced in future. Successful innovations often rely on the targeted combination of market pull and technology push activities. The method of design thinking" (Plattner, Meinel & Leifer, 2008) matches people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.

We as engineers are accustomed to arguing technical aspects. Nevertheless the architectural integration of technical components into the façade plays a major role in modern architecture. At this point the "theory of product language" offers interesting perspectives. In the mid-1970s Gros made a distinction between the practical functions of a product on the one hand, and the formal and communicative aspects, the so-called product language functions on the other (Gros, 1976).

According to the Kano model (Kano,1984) the factors for customer satisfaction can be differentiated into three categories (see Figure 2): "Must-haves" are not generally expressed openly, but if they are missing, this results in extreme dissatisfaction among customers. "Performance factors" are specified in detail and explicitly demanded. If these are well developed, they are rewarded by corresponding levels of customer satisfaction. The real differentiating feature is expressed in the unspoken "excitement factors". Customers are excited by practical functions which they do not expect, but which particularly meet their needs. In architecture excitement factors might hide behind outstanding customer services, thermal and visual comfort, as well as behind purely emotional factors such as formal aesthetic, indication and symbolic functions.

In the building industry innovations of great promise are based on a holistic design approach with a functionally optimized and architecturally integrated façade as an integrated part of it. To achieve that goal the project team has to be multidisciplinary with the architect as the master builder. Those teams are a typical example for the "open-innovation-principle". The team members have to imagine the world from multiple perspectives and not only rely on either/or choices. They create novel solutions that go beyond existing alternatives and do not simply work alongside other disciplines but are enthusiastic interdisciplinary collaborators. They have to open their innovation activities and connect internal and external ideas to profit from each other.

Global mega-trends	
Changing Demographics	Growing world population Aging societies Increasing urbanization
Globalization & Future Markets	Ongoing globalization BRIC - the new powerhouses Beyond BRIC
Scarcity of Resources	Energy Water Other resources/commodities
The Challenge of Climate Change	Rising CO_2 emissions Global warming Ecosystem at risk
Dynamic Technology & Innovation	Technology diffusion Power of innovation The age of life sciences
Global Knowledge Society	Knowledge base Gender gap Battle for talent
Sharing Global Responsibility	Transition to global cooperation Increasing power of NGOs Increasing philanthropy

Figure 1. Global mega-trends which will change the world (and the construction industry too) (N.N., 2011). (Source: Schueco International KG)

Functional Optimization of Buildings and Façades

It is important to realize, that we should not transfer our personal experience from the tiny world we are familiar with to the rest of the world. At least at this point we have to think out of the box in fact and take care of the local environmental factors, namely noise, wind, precipitation, cold, heat and radiation from the sun. The aim of climate-sensitive buildings is to minimize the negative effects of the climate using the smallest amount of resources and energy and at the same time to make maximum use of the positive effects, like sun, daylight and wind. Depending on the location the building envelope also provides more or less potential for the use of renewable energies (in particular for thermal or electric use of solar energy).

In the last twenty years we realized three different directions for the functional optimization of buildings: passive, active and cognitive building concepts (Heusler, 2013). In a passive building concept passive façade components seal off the interior from external factors as far as possible. Contemporary building technology ensures a comfortable interior environment. Conversely, in active building concepts dynamic façade components respond specifically to changing internal and external conditions. The aim here is to minimize the use of mechanical systems, especially by means of natural ventilation, passive use of solar energy and daylight. It is important to point out that the knowledge of users and/or operators of buildings, an aspect we may call "Operational Competence" becomes of increasing significance in active concepts. The most innovative building concept will inadvertently fail if it only performs in theory. Thus in many moderate climatic zones, optimum energy efficiency is provided by cognitive building concepts. Their façade and mechanical-system components with dynamically adjustable functions are connected to each other through an intelligent building automation system. Cognitive technologies can be characterized as those systematic means created by humans and used by them for the achievement of cognitive aims, including either cognitive states or cognitive processes that lead to such states or help significantly to reach them (Dascal & Dror, 2005). Adaptive components of the building skin are capable of reacting to non-continuous, changing external and internal conditions that are in many instances predictable and can be calculated, such as the case with annual or diurnal swings in meteorological conditions (i.e., solar altitude angle) or the times of a building's operation.

Figure 3. Building Excellence Concept 2025 for high-rise. (Source: Schueco International KG)

However, non-predictable weather and operational aspects - such as variations in cloudiness and spontaneous presence of users - should be included by means of appropriate sensors or via the Internet through the weather forecast.

Energy efficiency can be optimized if a designer widens the systemic boundaries – "thinking out of the box". For example the space between neighboring building parts may be designed as a large buffer zone, resulting in an atrium or mall-type space. Such buffer zones may be equipped with natural or mechanical systems to provide a general thermal environment ranging in air temperature between 15 and 30 °C annually, independent of external weather conditions. In an ideal scenario, the user will be enabled to control the components of the internal façades individually, without negative effects on energy consumption.

In the temperate climate zones (Central and Southern Europe, Southern Russia and most parts of the USA and China) buildings need good thermal insulation or good solar shading, depending on the season. In the subtropics (large parts of southern China and South America, as well as the southern states of the USA) the temperature in the coldest month does not usually drop below 5°C. The summers tend to be hot and humid. In contrast to the hot and dry zones the external air temperature rarely drops below 20°C at night, making efficient night-time cooling impossible. In many South-East Asian cities natural ventilation is often limited by insufficient external air quality or external noise. Condensation caused by damp internal air (when windows are open) is not a common phenomenon in the tropics, but it plays a significant role in temperate and cold climates (even in the daytime).

Our Building Excellence Concepts (see Figure 3) are designed to support outside the box thinking. We are trying to find advanced concepts for cognitive buildings that suit the local climate and specific purpose. Advanced parametric methods are advantageous for the holistic and detailed step-by-step analysis and optimization with respect to the following factors: cost-efficiency (investment, operating and maintenance costs), energy requirements (heating, cooling, ventilating, lighting etc.), environmental impact, room comfort (thermal, visual, acoustic etc.), ease of use/operation, cost and ease of maintenance, as well as the flexibility to change use and upgrade facilities. The level of priority given to the various planning criteria depends on whose point of view is being considered

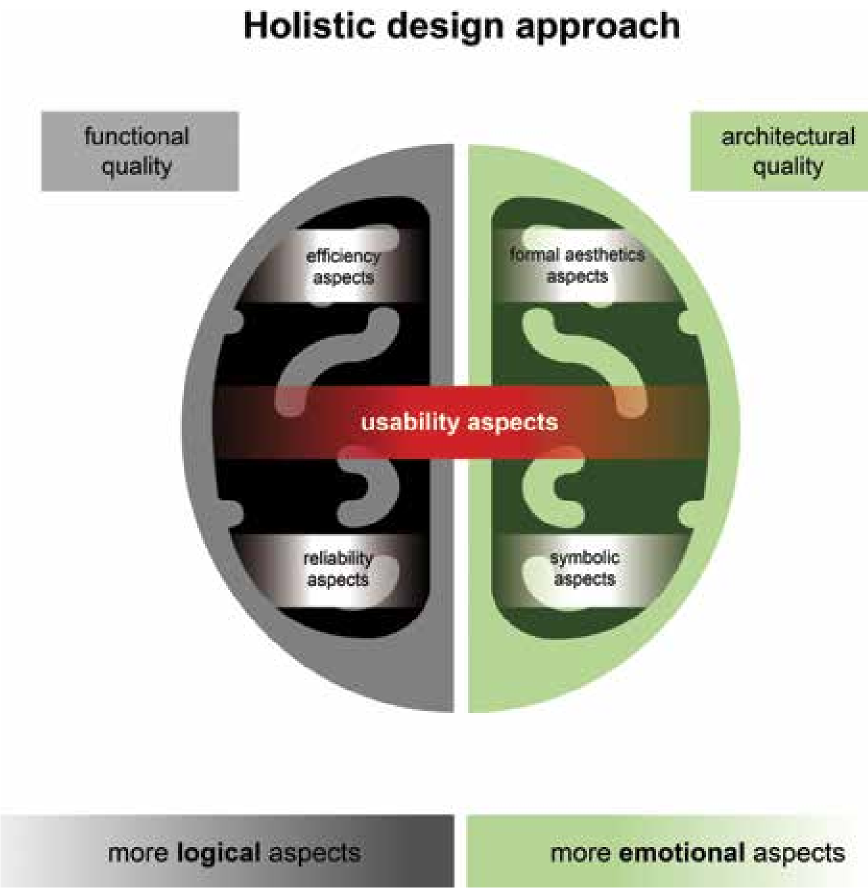

Figure 4. Holistic design approach for advanced façade design. (Source: Schueco International KG)

mostly. For example, the investor will primarily be interested in cost efficiency, meeting deadlines, and staying on budget. Clients and investors who think in the long term are more likely to focus on the needs of the future operator or tenant (operating costs, image, flexibility and so on) and the eventual user of the building (comfort, security). We found out in our previous team-discussions that since our social systems, tastes and the way we live and work seem to change with increasing speed, the flexibility of buildings is bound to become more significant. Cost-effective buildings are those that need only be equipped to meet current requirements, and then as those requirements change, can be altered quickly, easily and causing as little disruption as possible.

Functional and Formal Aspects of Façades

As we understood that great design satisfies both our needs and our desires (functionally and emotionally) our human-centered approach for advanced façade design and technology meanwhile takes into consideration the functional as well as the formal aspects of the façade. Following the "theory of product language" (Gros, (1976) we are dividing the formal aspects into aesthetic functions, indication functions and symbolic functions (see Figure 4).

Aesthetic functions distinguish two antagonistic principles: order versus complexity, and reduction of stimuli versus richness of stimuli in terms of shapes, color, texture and material for instance (the observer`s perspective).

Steffen analyzed innovations in the 20th century according to that theory (Steffen, 2000): Between the 1920s and the 1960s the modern avant-garde was quite successful in communicating the innovative character of modern architecture. The complexity of traditional forms was replaced by a high order of simple geometric forms and the elimination of ornamentation. Only after the International Style became dominant did high order turn into the negative. Accordingly, at the end of the 20th century the upcoming new architectural styles showed geometric complexity.

Indication functions visualize and explain the various practical functions of the facade and how it should be used (the user`s perspective). Symbolic functions are associated with objects in the imagination of the recipient or user, depending on the particular context. They refer to conceptions and associations that come to a person`s mind while contemplating an object: for example, societal, socio-cultural, historical, technological, economic and ecological aspects (the owner`s perspective). Accordingly architecture is a bearer of meaning, beside it`s utilitarian functions. In the end façades might be projection surfaces for meaning and the architect as the façade designer could act as the "story-teller" (see figure 5). And a successful story might even become a myth (Spath & Foerg, 2006).

Having said this the architecturally successful integration of functional components into the façade is essential. The actual challenge is to decouple the costs of the facade from its functional and formal quality. It is, however, crucial to remember that it is cheaper to make alterations at the beginning of the planning process, and that the costs increase as the planning activities progress. Making changes at the construction stage comes at a high price. Therefor in our approach for advanced façade design and technology the team considers several possible solutions that meet the specific conditions and

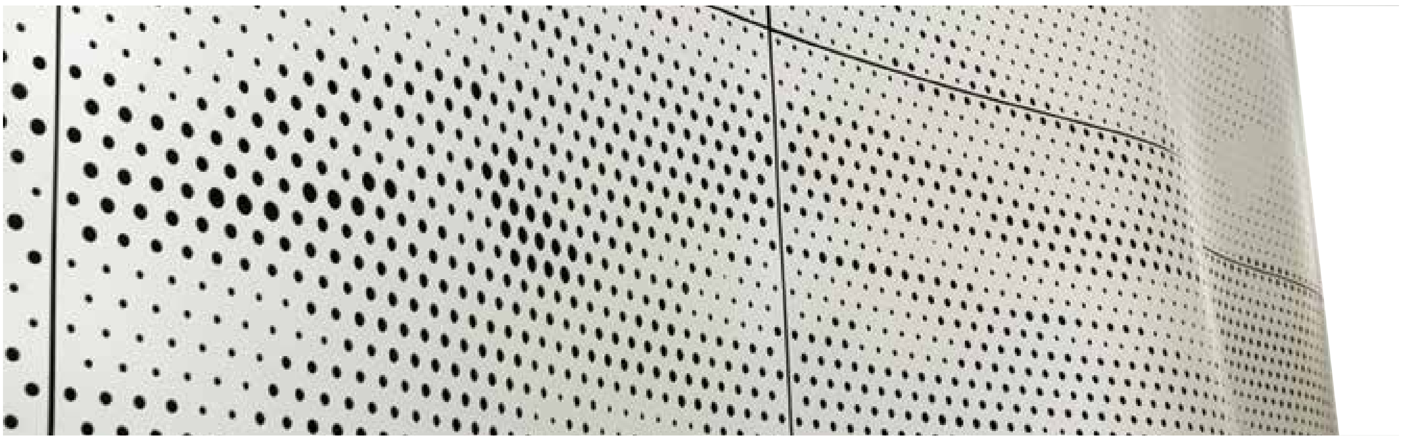
Figure 5. Opaque and semitransparent building skins with complex geometry ("Schueco Design Cover Concept" at trade fair Bau Munich 2015). (Source: Schueco International KG)

requirements defined in the specifications as soon as possible. In combination with advanced rendering and visualization tools the upper mentioned Building Excellence Approach allows designers to quickly explore a much larger solution space through virtual functional and visual mock-ups, as well as rapid prototyping models. It is the up to date basis for a fruitful and dynamic cross-disciplinary optimization process between architects and engineers.

Modular Systems Outside the Box

Besides functional and formal aspects our approach for advanced façade design and technology takes into consideration aspects of production, installation, maintenance and demolition of façades. By designing façades modularly with integrated and scalable functional groups, project specific solutions can be planned and executed more efficiently and with a higher quality. Modular systems - with optimized interfaces and standardized functional principles - are favorable for that purpose (see figure 6). The modules are transported in their entirety to site and fitted to consoles which were previously attached to and adjusted on the building`s structure. This design requires greater use of materials and more work in the factory not to mention experienced construction engineers. Unitized façades always require more planning and a corresponding amount of pre-planning and this may also need to be taken into account when projects are awarded.

Within cognitive buildings with adaptive building skins we are facing a large variety of mechanical, electric and electronic components as well as new materials. Different trades` competences are necessary for the successful solution of this cross-disciplinary challenge. For that reason in other industries "convergence" - the merging of trades as well as the blurring of existing lines, within which enterprises used to position

Figure 6. Modular façade with optimized interfaces and standardized functional principles (Media Banca, Milan, Italy). (Source: Schueco International KG)

themselves – has been on the rise for more than ten years. In the current façade industry the principle of convergence represents the next evolutionary step towards value-added solutions for the building's life cycle. By designing building skins modularly with integrated and scalable functional groups for each of the different trades, even complex project specific solutions can be planned and executed more efficiently and with a higher quality. The basis for this advanced concept is a flexible cooperation between the functional groups through optimized interfaces. Interoperable components lead to easier integration efforts. Modular systems - with standardized functional principles and carry-over parts across several series, system-specific construction characteristics as well as typical joining details and connection technologies - are favorable for that purpose. The benefits resulting from the high repetition factor and the simple, secure system solutions also mean lower training requirements for the employees of window and façade construction companies – whether engineers or skilled manual workers. The more extensive and well thought-out the system and the more intelligently the planners and designers use it in adapting the design to fit the project specific requirements, the greater the chance of combining the system components to meet technical and design requirements in an efficient and individual way.

Continuous Digitalization of the Process Chain

Our future will be based on the continuous digitalization of the process chain, connecting architects and engineers as well as main contractors, system suppliers, façade and maintenance companies with their specific activities spread all over the world (see Figure 7). This will radically transform their competence profiles. Within Cyber-physical systems (CPS) computational components are interacting with physical components. They are part of a globally networked future world, in which products, equipment and objects interact with embedded hardware and software beyond the limits of single applications. With the help of sensors, these systems process data from the physical world and make it available for network-

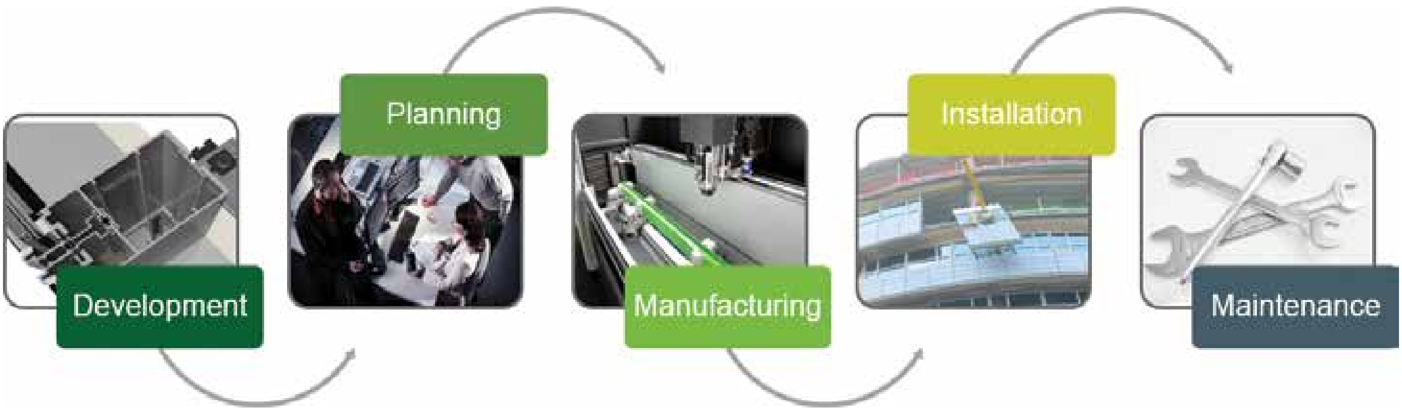

Figure 7. Digital Process Chain: continuous digitalization of the process chain, connecting architects and engineers as well as main contractors, system suppliers and façade companies. (Source: Schueco International KG)

based services, which in turn can have a direct effect on processes in the physical world using actuators (acatech (Ed.), 2011). In the near future the introduction of cyber-physical systems (CPS) into the facade business will comprise smart machines, storage systems, production facilities and building site terminals capable of autonomously exchanging information, triggering actions and controlling each other independently. CPS will shift the reliance on human decision making into new, more strategic aspects (N.N., 2013).

Cognitive technologies and cyber-physical systems will have an influence on the built environment. For architects and façade planners a holistic CPS-approach - merging digital and physical methods - deals with the optimization of the planning process as well as the fabrication- and assembly-process. In the end it can be advantageous to build the whole building including the CPS-system twice: First of all virtually (by means of augmented reality) and finally in reality. Within the real building process every step can be compared between the virtual model and the reality in the factory and on site (for instance through mobile 3D-scanning methods in combination with RFID tags and image recognition technology). Smart components of the façade will be uniquely identifiable. They know their own history, current status and alternative routes to achieving their target state throughout their lifetime from production through maintenance, functional updating and upgrading up to and including reuse or recycling. Smart assistance systems (e.g. cyber glasses) release workers and maintenance staff from extensive and sophisticated product manuals and from having to perform routine tasks, enabling them to focus on creative, value-added activities.

The research project 'KogniHome' (Ritter, 2014) has been launched to develop a networked home that supports the health, quality of life and safety of families, people living alone and senior citizens. One of the interesting research challenges is the objective that the future home needs to learn from its user and be able to adjust to new demands and phases of life. The aim is that inhabitants be able to communicate with the networked apartments with everyday language and gestures. The apartment will - amongst other means - communicate with its inhabitants in the form of an avatar – a digital person. In the end building techniques and methods are to be tailored to the people for whom the building is intended rather than matching the tenants to the newest possible techniques and methods. The challenge of cognitive technologies and cyber-physical systems will not just be to master technology and its economic use but the acceptance by society. As they discover and provide insight from vast amounts of information issues of privacy and security have to be addressed. The journey towards CPS-based building concepts with cognitive building skins will be an evolutionary process. At the same time it will radically transform architects', engineers' and workers' job and competence profiles. It is therefore necessary to implement appropriate training strategies and to organize work in a way that fosters learning (Kagermann, Wahlster & Helbig, 2013).

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