



# Solar integrated architecture in Scandinavia

An analysis of the design process

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Division of Energy and Building Design  
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Lund University  
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# Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

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Licentiate Thesis

## Keywords

Solar energy, design process, design tool, architecture, building, urban, actors, low energy, interviews, photovoltaics, solar thermal, integrated design process.

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# Abstract

Buildings account for a significant part of the energy use in Sweden. Our current built environment relies mostly on external energy sources rather than on local, on-site, energy sources. Future buildings will need to strongly reduce their energy need and produce the remaining energy demand with local, renewable energy sources. Solar energy has a large potential to produce this local, renewable energy with active solar technologies while contributing to the reduction of heating loads by means of passive solar strategies. However, solar energy is not given much priority in the design process today since it is a relatively new technology in the building sector.

For some buildings in Scandinavia, solar energy has been taken into account throughout the design process. In order to gain more insight and to identify drivers and barriers in the design processes of these buildings, semi-structured qualitative interviews were performed with the responsible architects. In total, 23 interviews were carried out in Denmark, Norway, and Sweden. Interviews were tape-recorded, transcribed, and analysed.

In the interviews, most architects indicated that it is important that all actors should be willing to implement solar energy: the architect, the client, the engineer, and the municipality. Solar energy was not prioritised by all clients because of its long payback time. Furthermore, architects felt that the role of municipalities regarding the implementation of solar energy into buildings was sometimes a stimulating and sometimes a limiting factor.

Teamwork was found to be crucial in the design process, but collaboration was not always flawless. New forms of collaboration were set up between architects and engineers, resembling the integrated design process. Many architects expressed that they need to gain more technical knowledge, while they would like to see that engineers start thinking more like architects in order to improve collaboration.

Architects had used several design tools in the design processes for which they were interviewed. While the traditional design tools such as 2D and 3D CAAD programs were used by almost all architects, Building Performance Simulation (BPS) tools were not optimally used, especially not for solar energy aspects. Rules of thumb for solar energy were used

very frequently, providing architects with rough estimates about the size, orientation and inclination of the system.

Architects also found that there was a lack of aesthetically attractive solar products, but noted a rapid development of new solar products in recent years.

The implementation of solar energy into our built environment needs to be incorporated at an early stage in the design process, preferably within the urban planning stage (if buildings are situated within an urban context). An early understanding of the solar potential of buildings will provide a clearer base for decision making in the design process. With the help of performance indicators, such as the solar potential and the annual electricity or heat coverage, different design alternatives of building blocks can be examined. A proposal of a working method has been developed to handle the integration of photovoltaics in the planning of new buildings in urban areas.

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# Nomenclature

BAM	Building Assessment Method
BIM	Building Information Modelling
BPS	Building Performance Simulation
EDP	Early Design Phase
IDP	Integrated Design Process
PV	Photovoltaic
ST	Solar Thermal



# Sammanfattning

Byggnader svarar för en betydande del av energianvändningen i Sverige. Vår byggda miljö är beroende av externa energikällor snarare än lokala energikällor. Framtida byggnader kommer att behöva kraftigt minska sitt energibehov samt producera det återstående energibehovet med lokala, förnyelsebara energikällor. Solenergi har en stor potential att producera denna lokala, förnyelsebara energi med aktiva solenergisystem samt bidra till minskat behov av tillförd energi med hjälp av passiva solstrategier. Solenergi är dock sällan prioriterat i designprocessen och skälen till detta är relativt okända.

Det finns dock exempel på byggnader i Skandinavien där man tagit hänsyn till solenergispekter genom hela designprocessen. För att få mer insikt och för att kunna identifiera drivkrafter och hinder i designprocesserna av dessa byggnader genomfördes semistrukturerade intervjuer med de ansvarige arkitekterna. Sammanlagt 23 intervjuer genomfördes i Danmark, Norge och Sverige. Intervjuerna spelades in, transkriberades och analyserades.

I intervjuerna visade de flesta arkitekter att det är viktigt att alla aktörer (arkitekt, beställare, ingenjör, kommun) är villiga att ta hänsyn till solenergi. Solenergi har inte prioriterats av beställaren på grund av en lång återbetalningstid. Arkitekter upplevde att kommunernas roll i genomförandet av solenergi i byggnader ibland är stimulerande, ibland begränsande.

Teamwork upplevdes som avgörande i designprocess men samarbetet var inte alltid smidigt och felfritt. Nya former av samarbete mellan arkitekter och ingenjörer skapades, som liknar den integrerade designprocessen (IDP). Många arkitekter uttryckte ett behov att få mer teknisk kunskap samtidigt som de ville att ingenjörerna skulle börja tänka lite mer som arkitekter för att få ett bättre samarbete.

Arkitekterna använde flera designverktyg i designprocesserna. Medan de traditionella designverktyg, som 2D och 3D CAD-program, användes av nästan alla arkitekter blev simuleringsverktyg inte optimalt utnyttjade, särskilt inte för solenergi. Tumregler för solenergi användes däremot ofta, vilka ger arkitekter grova uppskattningar om systems storlek, orientering och lutning.

Arkitekterna upplevde också en brist på estetiskt tilltalande solenergi produkter men märkte en snabb utveckling av nya produkter under de senaste åren.

Implementeringen av solenergi i den byggda miljön måste komma in i ett tidigt skede i designprocessen, helst i stadsplaneringsskede. En tidig förståelse av byggnadens solpotential kommer att ge en tydligare grund för beslutfattandet i designprocessen. Med hjälp av prestandaindikatorer, som solpotential och den årliga täckningsgraden av el och värme, kan man undersöka olika designalternativ av byggnader. Ett förslag på arbetsmetod har tagits fram som behandlar integrering av sol, vid planeringen av nya byggnader i stadsmiljö.

# List of articles

This licentiate thesis was published partly as peer-reviewed conference and journal articles listed below: (see Appendix for original versions)

## Conference Papers

- I Kanters, J., & Horvat, M. (2012b). Solar energy as a design parameter in urban environments. Accepted for publication in proceedings from *SHC 2012: International Conference on Solar Heating and Cooling for Buildings and Industry*, San Francisco.
- II Kanters, J., & Horvat, M. (2012a). The design process known as integrated design process: A discussion. Accepted for publication in proceedings from *SHC 2012: International Conference on Solar Heating and Cooling for Buildings and Industry*.
- III Kanters, J. (2011). Adequacy of current design tools and methods for solar architecture – results of IEA-SHC Task 41’s international survey. Proceedings from *PLEA 2011: Passive and Low Energy Architecture*, Louvain-la-Neuve, Belgium.

## Articles in peer-reviewed journals

- IV Kanters, J., Dubois, M-C., & Horvat, M. (2012). Tools and methods used by architects for solar design. *Energy and Buildings*. Available online 29 June 2012.
- V Kanters, J., Dubois, M-C., & Wall, M. (2012). Architects’ design process in solar-integrated architecture in Sweden. *Architectural Science Review*, 1-11. doi: 10.1080/00038628.2012.681031

Each of the articles in the appendix deals with topics related to a chapter in this thesis.

The article “Adequacy of current design tools and methods for solar architecture – results of IEA-SHC task 41’s international survey“ (Article III) shows the results of a survey performed within the framework of IEA

SHC Task 41 and is related to Chapter 3. This survey had the objective to identify and address obstacles that architects are facing in solar design.

The articles “Architects’ design process in solar-integrated architecture in Sweden” (Article V) and “Tools and methods used by architects for solar design” (Article IV) both describe the results of the interviews conducted with architects in Denmark, Norway and Sweden (as described in Chapter 4). The first article focuses more on the situation in Sweden, while the second one focuses on the Scandinavian situation. A third article called The design process known as integrated design process: A discussion (Article II), provides an overview of some critical points of the Integrated Design Process. The interviews made in this research are part of the input of this article.

The article entitled Solar energy as a design parameter in urban environments (Article I) deals with the parametric study described in Chapter 5.

# 1 Introduction

In this section, the background, the main objectives and the methods of this research are presented.

## 1.1 Background

Existing buildings account for over 40% of the world's total primary energy use and 24% of greenhouse gas emissions (Wall, Windeleff, & Lien, 2009). A combination of making buildings more energy-efficient and using a larger fraction of renewable energy is therefore the key to reducing the non-renewable energy use and greenhouse gas emissions. Also, in Europe, the ambitious 2020 EPBD directive (European Parliament, 2010) requires that all new buildings use nearly zero energy by 2020.

### 1.1.1 Solar energy as an energy source

In this research, the main focus is on the implementation of solar energy into architecture, cleverly taking into account the conditions of both passive and active solar energy (Kanters, Dubois, & Wall, 2012). Architects have the opportunity to change our built environment, but unfortunately, the actual application and integration of solar systems in buildings is lagging behind compared with the technical development of these systems. The main reasons for this have been stated by the IEA: insufficient technical knowledge, fear to use new technology, economic issues, and aesthetic limitations (Wall et al., 2009). Architects could clearly contribute to bridge the gap that consists in the need for integration of solar systems and an aesthetically pleasing environment.

The sun provides a great amount of energy. The report *RE-thinking 2050; a 100% Renewable Energy Vision for the European Union* (EREC, 2010) shows that solar energy could theoretically provide 2850 times the current global energy needs, which is far more than other renewable energy sources (Figure 1.1). The theoretical energy potential of these energy

sources provides the upper limit of what can be exploited. The technical potential is the amount of energy that can really be exploited with the latest technology.

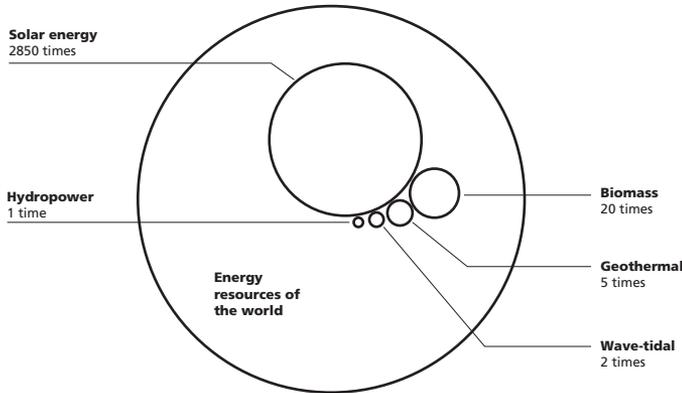


Figure 1.1 Energy resources of the world (adapted from EREC, 2010)

The potential of solar energy is far from fully exploited. In Europe, PV contributed 17% of the installed capacity of all energy sources in 2009 (EREC, 2010), mainly in Germany, Italy, and the Czech Republic (EPIS, 2010). The European Union has set goals to reduce energy use and thus greenhouse gases. The contribution of solar energy (both photovoltaics and solar thermal systems) in the energy supply side needs to be exploited to its full potential in order to reach these goals.

The contribution of PV to electricity production has to increase from 0,5 Mtoe (one million tonne of oil equivalent) in 2007 to 116 Mtoe in 2050 in order to meet the European goal (EREC, 2010). For solar thermal, this contribution has to grow from 0,9 Mtoe in 2007 to 122 Mtoe in 2050. These increases (PV: 232%, ST: 124%) are amongst the highest growth levels compared to other renewable sources.

Despite its northern geographic location, the potential of solar energy in Sweden is still significant; the solar radiation level in the most populated parts of Sweden is between 1000-1100 kWh/m<sup>2</sup>year on a horizontal, unshaded, plane as is shown in Figure 1.2. In this Figure, systems are considered to have a performance ratio of 0,75 kWh/kW<sub>peak</sub> (Performance Ratio = Final yield / Reference yield). The performance ratio is dependent on all pre-conversion losses, inverter losses, thermal losses and conduction losses. On average, existing office buildings in Sweden use around 150 kWh/m<sup>2</sup>year (Energimyndigheten, 2009). Highly energy-efficient office buildings which are being designed and built now in Sweden can reach an energy use of less than 50 kWh/m<sup>2</sup>year (Flodberg, 2012). With PV

having an efficiency of 15%, it should be possible to extract  $150 \text{ kWh/m}^2$  electricity, which means much more than the average energy use per square metre in a highly-efficient office building. It needs to be kept in mind that either energy storage or a connection to the grid is necessary to balance the annual energy production and the energy need. Another constraint is that in the case of apartment buildings, it is necessary to make use of facades which might be shaded by other buildings.

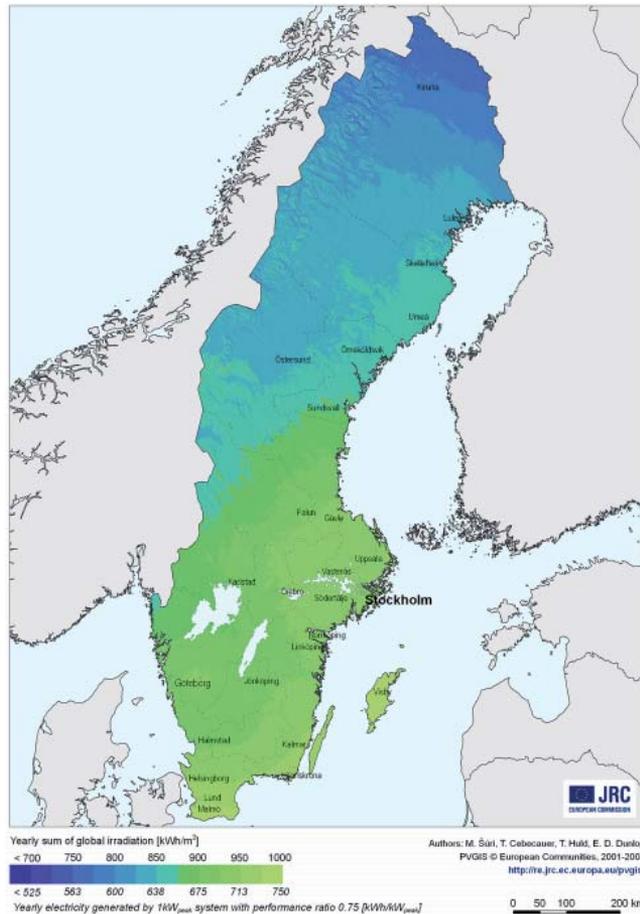


Figure 1.2 Global irradiation levels on a horizontal plane in Sweden

### 1.1.2 Energy use and supply in Sweden

The proportion of renewables in Sweden's total energy supply was over 30% in 2008 (51% for electricity) and was mainly produced by hydro-power (Energimyndigheten, 2009). Solar energy does not play a fundamental role in the current energy supply in Sweden (see Figure 1.3). The contribution of solar energy is not mentioned in these figures, since its contribution is negligible.

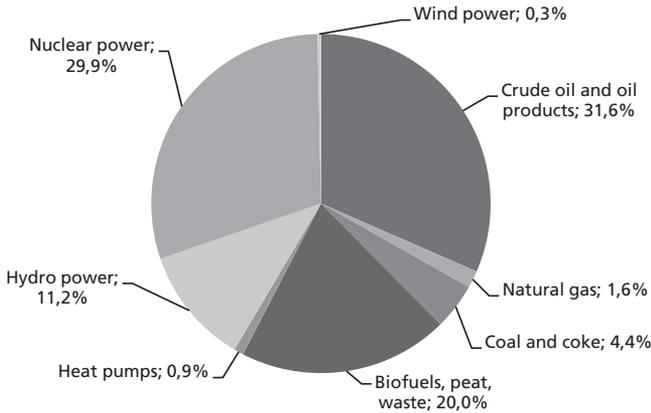


Figure 1.3 Energy supply in Sweden (without distribution and conversion losses), 2008 (Energimyndigheten 2009)

An overview of the energy use for domestic hot water (DHW) and space heating excluding household electricity of Swedish buildings (single-family houses, apartment buildings and offices) shows that the energy intensity (the amount of energy used per square metre) has decreased in recent years (Figure 1.4). A typical single-family house consumes 175 kWh/m<sup>2</sup>year, apartment buildings 160 kWh/m<sup>2</sup>year and offices 150 kWh/m<sup>2</sup>year, on average (Energimyndigheten, 2009).

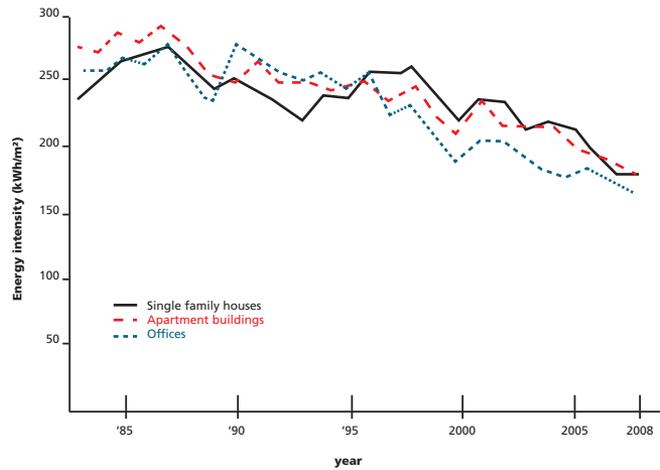


Figure 1.4 Energy intensity for DHW and space heating in single-family houses, apartment buildings and offices (adapted from *Energimyndigheten 2009*)

Even though the energy intensity for DHW and space heating is decreasing, the need for electricity did not decrease according to the same trend. In some cases, household electricity was even increasing (Figure 1.5); this is mostly due to the growing number of appliances and IT, which all require more electricity. Moreover, an increase in the number of square metres used per person and a growing population will inevitably lead to a constant energy demand, despite reductions in energy intensity.

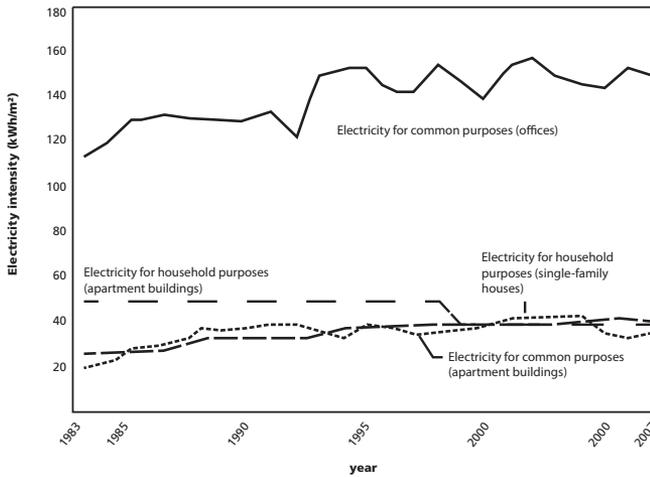


Figure 1.5 Household electricity intensity throughout the years in Sweden (adapted from Energimyndigheten 2009)

## 1.2 Objectives

The first aim of this research was to gain an insight, by means of interviews, into the way in which solar energy is at present implemented into the design process of Scandinavian architects and urban planners. The objectives of the interviews were to identify barriers and drivers for solar energy, to identify forms of collaboration with other actors in the design process, and the use of design tools. The second aim was to start development of a working method for implementing solar energy in the design process from large to small scale.

With the literature review and the interviews, it was expected that sufficient knowledge would be gained to start development of a design method for implementing solar energy systems in buildings.

## 1.3 Method

In the first phase, a literature review was carried out, with the main objective to analyse the current knowledge about the design process, BPS tools, the implementation of solar energy, and architectural education.

In the second phase, 23 semi-structured interviews were conducted in Denmark, Norway, and Sweden in order to analyse the design process of solar integrated projects in Scandinavia. Interviews were held with architects, of whom two worked at urban planning departments. Besides general barriers and drivers of solar energy, the design process of a particular solar integrated project designed by the interviewee was discussed.

In the third phase, combining the results of phases 1 and 2, a preliminary method for analysing the solar potential of buildings was developed. Earlier methods to analyse the solar potential of buildings were taken into account in developing this method. The method is based on the BPS tool Ecotect.

## 1.4 Limitations

The focus in this research is on the architect's role in the design process. The role of other actors in the design process is therefore discussed through the experiences of architects, not directly from the other actors' perspectives. Another limitation is that the developed design method focuses on new buildings, not on existing buildings.



## 2 Theoretical framework

### 2.1 Concepts in low energy buildings

New concepts of low energy buildings have emerged in the past decades. Energy-efficient buildings, sustainable buildings, low energy buildings, passive buildings, net-zero energy buildings, plus-energy buildings etc. were introduced in order to describe buildings in which an energy use lower than that in conventional buildings was somehow targeted. Two of these concepts which are used extensively nowadays are passive buildings and net-zero energy buildings. The passive house concept was introduced during the 1980s and has been mainly developed in Germany, while the concept of net-zero energy buildings is more recent. It is closely connected to the introduction of the EU Directive on Energy Performance of Buildings which specifies that by the end of 2020, all new buildings should be “nearly zero energy buildings” (European Parliament, 2010).

#### Passive buildings

The basic idea of a passive house is to ‘improve the thermal performance of the envelope to such a level, that the heating system can be kept very simple’ (Feist, Schnieders, Dorer, & Haas, 2005). However, in colder climates, additional space heating might be needed. The concept was launched in 1988, and in 1990, the first passive house was built. The main lesson learnt from these first passive houses was that a well-functioning passive house requires a highly insulated climate shell and a high-efficiency heat exchanger in the ventilation system (Janson, 2010). Later, other passive houses were built and monitored, using 50% less energy than conventional buildings. Research has shown that several recently built Swedish passive houses have an energy intensity between 36-66 kWh/m<sup>2</sup>year (excl. household electricity) (Janson, 2010), while according to the Swedish building code BBR 19, a maximum of 90 kWh/m<sup>2</sup>year is allowed (in the southern climatic zone) (Boverket, 2011). After the energy use for heating and DHW started to decrease, the amount of energy used for household electricity started to rise (Janson, 2010). In different countries, different definitions of passive houses have been developed, but the basis remains that the building

envelope should be well-insulated and airtight as well as having heat-recovery on the ventilation system. These requirements on the climate shell have a rather large influence on the architecture of those buildings, mostly on the thickness of outer walls, and window-to-wall ratios.

### Net zero energy buildings

A net zero energy building (NZEB) is a grid-connected building with an annual energy balance of zero. It is understood as a building with greatly reduced energy demand that can be balanced by an equivalent on-site generation of energy from renewable sources (Sartori et al., 2010). The concept can be visualised in Figure 2.1.

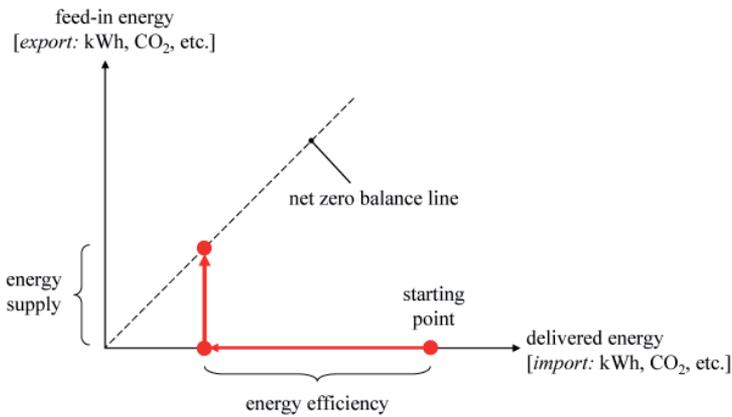


Figure 2.1 Graphical representation of the net zero balance of a NZEB (Sartori et al. 2010)

There is not yet an internationally agreed definition for NZEBs, even though the concept of the NZEB has been discussed for a while and is the subject of an international research project (IEA SHC Task 40 / ECBCS Annex 52). Designing a NZEB has an impact on the architecture of such a building; the passive aspect has consequences for the dimensions of outer walls, size of windows etc., while the active energy production in a NZEB by means of PV and ST has an impact on the architecture of the building.

## 2.2 Solar integration strategies in architecture

Architects could contribute to the increased use of solar energy in our built environment through architecture and urban planning. Active solar technologies have good opportunities to be applied in the urban environment, namely in buildings and urban structures, in view of their flexibility, both in form and function (POLIS, 2010).

In order to promote the use of solar energy in buildings with a high-quality architecture, Task 41 of the IEA Solar Heating and Cooling programme was carried out from 2009-2012, called Solar Energy and Architecture (Wall, 2012). Members of the task were from fourteen countries and the participants were architects, engineers, and researchers. The task was divided into three subtasks, each of them focusing on one aspect of the use of solar energy in buildings:

- Subtask A: Architectural quality
- Subtask B: Tools and methods for architects
- Subtask C: Case studies and communication guidelines

The results of this task include an inventory of computer tools, a literature review, a survey on solar system perception and use by architects, a survey on needs regarding tools for solar design, recommendations for computer tool developers, different guidelines for solar systems, and an extensive showcase of inspiring solar architecture (International Energy Agency, 2009).

There are several architectural integration strategies of solar energy that will be discussed here as being the passive and active use of solar energy. According to Weller (2010), active solar systems can be physically implemented in several ways;

- Subjugation: installations placed on or in front of a building without any architectural goals, with the sole tasks to produce energy.
- Domination: when the solar technology has a decisive effect on the design of a new building, i.e. its orientation with respect to the sun, its volume and the configuration of the building envelope.
- Integration: an integrated solar energy installation is in harmony with its building; the solar technology and the structure are equal partners in a symbiotic system (It also satisfies architectural functions of the building envelope).

- Subordination: if the solar energy system is hardly apparent because of its shape and size, its position with respect to the observer and public spaces, or its colour.
- Imitation: The imitating system tries to copy traditional forms of construction, replace their functions and at the same time add an active solar layer.

Passive solar heating in architecture consists of using solar gains for heating and daylighting. Solar penetration needs to be planned carefully: too much glass could overheat the building during the summer and causes visual discomfort. Insufficient glass ratios could make the building use more electric lighting. Therefore, an architect needs to be aware of the location of the building, solar conditions, climatic conditions, and building use in order to make appropriate decisions regarding passive solar energy use.

Another important point which needs to be considered by the design team is daylighting: placing windows or openings in such a way that daylight provides effective internal lighting. In order to reduce the amount of energy used by artificial lighting, the size and location of openings could contribute to this reduction by providing sufficient lighting levels. However, when openings get bigger, the risk of overheating occurs, as well as the risk of visual discomfort and discomfort in the winter due to cold draughts (Dubois & Blomsterberg, 2011).

### 2.2.1 Integrated passive solar techniques

Passive solar gains can meet 10-15% of the total heat demand in current buildings (Santamouris, 2003), and up to 50% in well-insulated buildings (Roulet, 2004). However, the contribution of passive solar gains is left out of all national and European energy statistics since these only consider the supply side. How can we maximise the passive use of solar energy in order to reduce the heat demand in buildings? Integration of passive solar strategies into the building requires a careful approach on several basic parameters of the building right from the early beginning of the design process. Passive solar design is low cost if it is incorporated in the early design stage; it requires placing the windows so as to maximize winter solar gains and solar protection to control the summer gain, and by choosing materials that provide thermal mass to store heat (Garrett & Koontz, 2008).

The building's environment is important for the heat balance of buildings; trees and green spaces contribute significantly to the cooling of the built environment and to energy saving, since they can provide solar protection for individual houses during the summer period (Gordon, 2001).

Solar radiation in dense urban environments is often limited which is the result of shading by neighbouring buildings, building orientation, urban regulation constraints, constraints of size, and limited space for solar collection compared to the area of building.

Another factor which influences solar gains are materials: the optical characteristics of materials used in the outer facade of buildings may have a very important effect on the urban energy balance and performance of buildings (Gordon, 2001).

### 2.2.2 Active solar systems and their integration

The output of active solar systems may be heating, cooling, and electricity. Systems which deliver electricity are photovoltaic (PV) systems, systems which produce heat are solar thermal (ST) systems, and systems are called hybrid when they produce both forms of energy (see Figure 2.2 for an overview of common active solar systems).

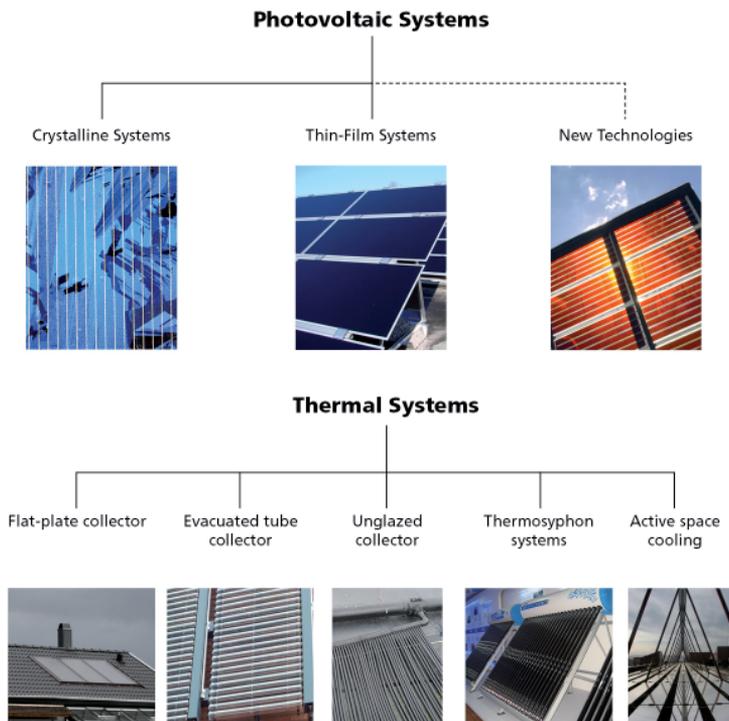


Figure 2.2 Overview of solar thermal and photovoltaic systems

## Photovoltaic solar systems

Photovoltaic solar systems (PV) can be divided into two major groups; crystalline silicon and thin-film technology (Figure 2.2). New cell types (mainly the dye-sensitized solar cells) are being developed but are not yet mature for large-scale production. The crystalline group is the oldest technology and has been most applied. The technology behind PVs is closely linked with the development of quantum mechanics and microelectronics (Gordon, 2001). The actual process inside the PVs functions as follows: photons, on entering a photovoltaic solar cell, release electrons and then flow through an electrical load connected between the positive and negative terminals of the solar cell (see Figure 2.3). The appearance of polycrystalline cells is frost-like, thin-film technology has a uniform appearance with a dark grey-black, red-brown or blue-violet colouring.

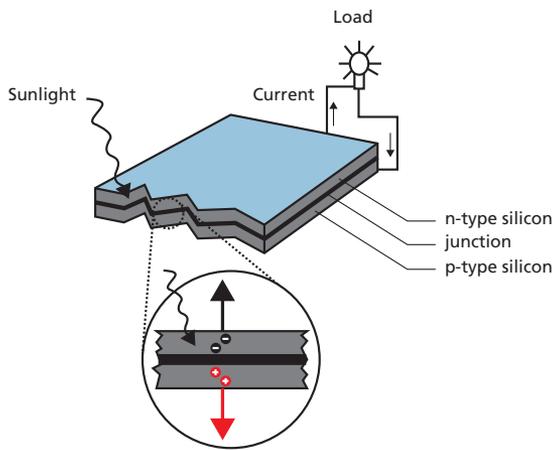


Figure 2.3 Principle of photovoltaic systems (adapted from IEA-PVPS 2010)

PVs have different efficiencies; systems with multi-junction concentrators (modified thin-film systems) can reach 42,4% efficiency (NREL 2010). The highest efficiency amongst crystalline cells is currently 27,6%, while for thin-film technologies it is 20,3%, and for emerging PV technologies the highest efficiency is 11,1% (NREL 2010). These values are often obtained under perfect laboratory conditions and for prototypes.

With prices for active solar technologies declining, several countries will soon reach a point where the costs of solar PV electricity becomes competitive with conventional grid supplied electricity: a term called grid-parity (Branker, Pathak, & Pearce, 2011). As an example, this point might be reached in 2013 in Italy (Table 2.1)(EPIS, 2010).

Table 2.1 Date when grid-parity is reached in several countries (EPIS, 2010)

	France	Germany	Italy	Spain	United Kingdom
Residential	2016	2017	2015	2017	2019
Commercial	2018	2017	2013	2014	2017
Industrial	2019	2019	2014	2017	2019

Cost competitiveness is an important issue regarding PV since many stakeholders are sceptical about PV because of its high costs. Besides, national conditions can vary quite heavily. The local power grids need to be adapted in order to be able to accept solar electricity into the grid and energy companies need to provide financial incentives to their clients who are willing to deliver this energy. Also, in most northern countries, there is a mismatch between production and use, since more solar energy is generated during summer when the use is not that high, and during winter evenings, the energy production is at its lowest when the energy demand reaches its peak. An efficient storage of energy and a connection to a smart grid are therefore necessary to flatten out these seasonal fluctuations.

### Solar thermal systems

Solar thermal systems (ST) can be divided into the following categories (Figure 2.2);

- flat-plate glazed collectors
- unglazed collectors
- evacuated collectors
- flat-plate air heating collectors
- thermosyphon systems
- solar air-conditioning

The efficiency of ST systems is dependent on the temperature difference between the solar panels and the ambient temperature (the efficiency of the most common thermal systems is shown in Figure 2.4).

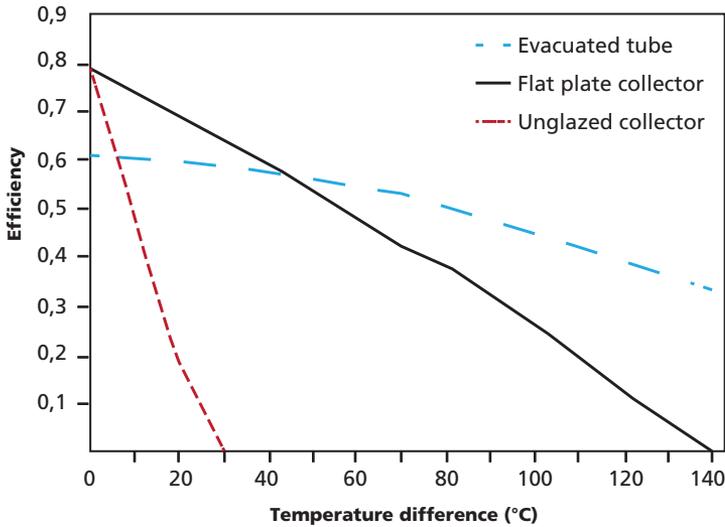


Figure 2.4 Efficiencies of the different solar thermal systems (adapted from Andrén 2003)

### Flat-plate glazed collector

A flat-plate collector is an energy conversion system that absorbs solar radiation and transfers the energy to a fluid passing through the collector. A flat-plate collector is able to collect both direct and diffuse components of radiation and is used primarily for air or water heating (see Figure 2.5). They have the largest heat absorbing area compared with all other thermal systems (Gordon, 2001).

A flat-plate collector is built as follows (top to bottom): high transmission cover, absorber plate coated with a high absorptance (solar) and low-emittance (infrared) layer, high conductivity absorber plate with fin and tube construction, fluid passage in good thermal contact with the absorber plate, weather-proof casing with insulation behind the absorber plate.

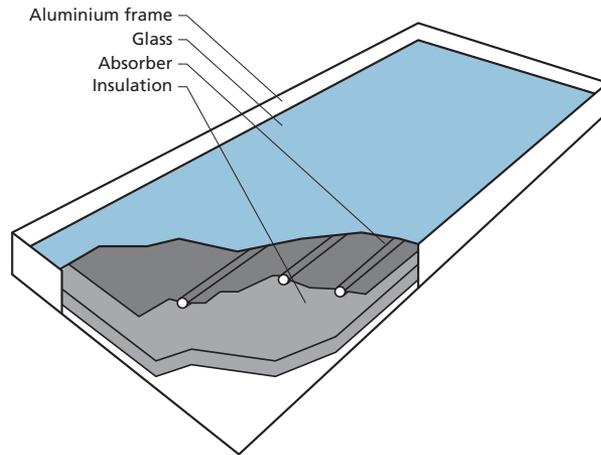


Figure 2.5 Illustration of a flat-plate collector

### Evacuated collectors

Evacuated tubular collectors consist of an absorbing surface mounted in a vacuum to eliminate convection heat loss (see Figure 2.6). Two forms of evacuated tubular absorbers are used; the all-glass Dewar type and the single glass envelope metal-fin-in vacuum type (Gordon, 2001). The metal-fin group consists of three different types of construction; U-tube, straight pipe and heat-pipe.

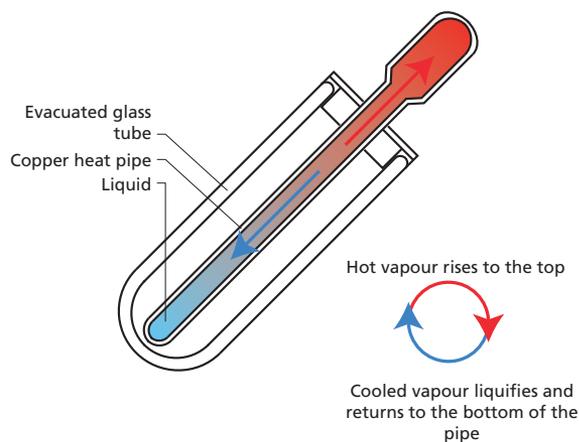


Figure 2.6 Illustration of an evacuated tube collector



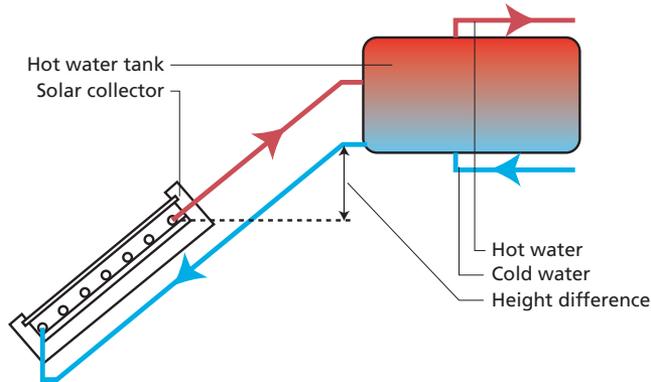


Figure 2.8 Illustration of a thermosyphon system

### Active solar space cooling

Cooling and refrigeration using active solar cooling systems can provide a year-round utilisation of collected solar heat, thereby significantly increasing the cost effectiveness and energy contribution of solar installations (Santamouris, 2003).

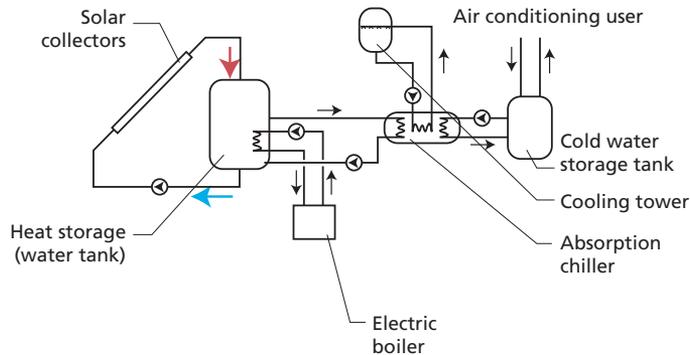


Figure 2.9 Illustration of a thermal cooling system

Active solar space cooling can be divided into three categories: solar sorption cooling, solar-mechanical systems and solar-related systems (Florides, Tassou, Kalogirou, & Wrobel, 2002).

Solar sorption cooling makes use of sorbent materials which have an ability to attract and hold other gases or liquids. Two separate systems can be classified; absorption systems and desiccant systems. Absorption systems

use heat from the sun to separate a refrigerant fluid from an absorbent fluid. The evaporated refrigerant is then condensed in a chiller to produce cold water. Indoor air is blown over this chilled water, which is used for space cooling (Henning, 2007). Desiccant systems contain either a solid or a fluid, which rotates on a wheel into the stream of an air flow. The desiccants lower the humidity and cool the air. (Figure 2.9).

Solar-mechanical systems utilise a solar-powered mover to drive a conventional air conditioning system (Florides et al., 2002), which can be done by converting solar energy into electricity by means of photovoltaic devices, and then utilise an electric motor to drive a vapour compressor.

Solar-related air conditioning are systems in which some components installed for the purpose of heating a building can be used to cool without the direct use of solar energy (Florides et al., 2002). Examples of these systems are 1) heat pumps, 2) rock bed generator, 3) passive cooling.

## 2.3 Solar integration in urban planning

Throughout history, urban planners already implemented solar energy. Perlin & Butti (1981) described that already 6000 years ago, the Chinese oriented their houses in such a way that solar energy was taken into account. Wide streets provided enough daylight for all surrounding houses. The Greeks built their houses with courts, letting in the sun in the winter and blocking the sun in the summer. The Romans discovered that they could trap heat from the sun with big glazed facades. The Modern Architecture movement took the principles of solar architecture into account by orienting buildings in the South direction and by spacing all buildings in such a way that they were not shading each other.

Cities are now home to nearly 80% of the European population, producing 75% of all CO<sub>2</sub> emissions (POLIS, 2010). Worldwide, half of the population lives in cities and this is likely to increase to 75% by 2050 (United Nations, 2004). The use of renewable energy should therefore not only be limited to buildings, but city and urban planners should also take solar energy into account. By focusing on both cities and buildings, the total amount of energy used in buildings can be substantially reduced, and more dense settlements will reduce the amount of energy used for transportation (Hestnes, 1999). According to several authors, the urban scale has been neglected in the debate on energy consumption and climate change (Lehmann, 2008; Ratti, Baker, & Steemers, 2005), although data showed that savings in energy cost of 20-50% are possible through integrated planning with carefully considered site orientation and passive strategies (Lehmann, 2008).

Implementation of solar energy in urban planning needs to be considered carefully and has rather significant consequences on the formal constellation of cities in order to be fully effective.

### 2.3.1 Tools for analysing the solar potential of existing urban fabric

In the past, assessment of the solar potential in urban conditions has been difficult because of the complexity of modelling the 3D urban geometry (Ratti et al., 2005). In the last decade, many new methods have become available, due to the increasing available computer power or due to optimisation methods.

Currently, several cities and regions have visualised the solar potential of the existing urban geometry by mapping the solar radiation in an interactive way. In the case of analyses done by cities like Graz (Austria), Lyon (France), the island of Madeira (Portugal), New York City (USA), Munich (Germany), and Vienna (Austria), a GIS-system (Geographical Information System) was used as basis for these analyses. As an example, a solar map is shown in Figure 2.10, based on aerial photography which provided data for the assessment of the solar potential of the roofs in the city of Vienna (Kapfenberger-Pock & Horst, 2010).



Figure 2.10 Map of the city of Vienna (Austria) and the solar potential of roofs

These mapping tools provide very useful information for everyone interested in harvesting solar energy, visualised in a simple and intelligible way. With these maps, even a layman can judge if a building's roof is suitable

for solar energy, without the need to have specific technical knowledge. One major drawback of this solar mapping combined with GIS is that it only takes into account the roof surface and not the facade area. On the other hand, the highest annual yield of solar energy is generally on roof surfaces, not on facades.

Although solar maps implemented in GIS-system give architects and urban designers valuable information about the suitability of the existing buildings to harvest solar energy, it is not really a design tool and it is limited to the existing building stock.

One important design –non-computerised- tool for solar urban planning was developed already in 1974 by Knowles (2003), and is called the ‘solar envelope’. The solar envelope is a 3D surface, on a given site, that does not obstruct more than n hours of sun onto the adjacent site (Morello & Ratti, 2009) and which is visualised as a 3D frame (see Figure 2.11).



*Figure 2.11 Knowles' solar envelope applied to an urban plan (University of South California)*

Later, Knowles' idea was extended into ‘solar rights envelopes’ and ‘solar collection envelopes’ by Morelli and Ratti (2009). The solar right envelope is the same as the solar envelope, and the solar collection envelope is an envelope examining the total number of sun-hours collected by a particular urban 3D surface. Together, these two elements construct ‘iso-solar surfaces’, 3D geometric envelopes which receive equal amounts of solar energy. This methodology makes calculations of solar envelopes over complex urban sites easier and it provides the actual irradiation and illumination of the city.

### 2.3.2 Tools of the architect

The first buildings were built by the architect. Later on, the architect started to make drawings before building, which became an important paradigm

change in the architect's working method. Faced with more demands and subjects to evaluate, the architect needed more tools other than just drawings. The use of simulation and visualisation tools can help architects to choose between several design alternatives in order to judge which design alternative is a good solution for its complex problem. The process of validating different design alternatives can be called evidence-based design (Hamilton, 2004). With the rise of IT, new computer tools were developed to be used by architects and engineers. Drawing programs (CAAD), BPS tools and visualisation programs have found their way into all architectural practices. The benefits of these programs are significant: predictions about construction and energy use can be made without having to perform manual calculations, visualisation programs make it possible to visualise a building and most of all CAD programs have made the production of construction documents more efficient. Drawing programs are known as CAAD (Computer Aided Architectural Design). They were introduced with the launch of the first CAAD application in 1975. They are widely used in everyday practice today. A new type of CAAD programs are the so-called Building Information Model-programs (or BIM), which are a digital building environment containing form, behaviour and relations of parts and assemblies (Eastman, 1999). Architects and other participants can work together on a 3D building model and can exchange information about the building and building components. This way, all collaborators can gather information when they want and they are not dependent on the architect to deliver drawings to them. In the USA, almost 50% of the architectural offices are using BIM (AIA 2009). BIM is often used in an Integrated Design Process (IDP), where participants work together to establish a sustainable building and therefore need to exchange a lot of information. While many CAAD programs were only used for drawing, a series of developments in the past few years changed that: there are many CAAD programs today which include a connection to an energy simulation program (Dubois & Horvat, 2010). The problem here is that many CAAD tools are more suited for detailed design than the early design phase (EDP) even if active solar features are linked to a 3D environment and it is in the EDP that the greatest gain can be made when it comes to the energy performance of the building (Dubois and Horvat, 2010, Schlueter and Thesseling, 2009, Ellis and Mathews, 2001).

A large number of studies have been performed on the development of new BPS tools which can be incorporated in the design process. Over the past 50 years, hundreds of building energy programs have been developed and are in use. The main BPS tools are the whole-building energy simulation programs, providing key performance indicators such as energy demand, temperature, humidity and costs (Crawley, Hand, Kummert, & Griffith, 2008). Because of the large number of BPS tools, it is hard

for architects and engineers to know which program will fit their working method best. Another complicating factor is the fact that vendors of simulation programs all use their own language when describing their products, which makes it harder for architects to choose (Crawley et al., 2008). Holm (1993) wrote that the designer's approach, working from the whole towards the detail, is contrasted with the way analytical models are typically structured, which has led to the development of a number of simulation tools which overlook the real needs of the industry. During a congress already in 1987, the following needs for a good design tool were identified; 1) the design tool should be user-friendly, 2) it should be of a general nature to facilitate 'what if' alternatives readily, 3) calculation speed is a higher priority than accuracy, 4) input formats should be user oriented. Holm adds that these points seem appropriate, but they also raised new questions: 1) what is user-friendly to an architect?, 2) how much accuracy can be sacrificed in favour of speed?, 3) at what stage do we expect the architect to interrupt his design activities to concentrate on simulations?, 4) how do we prioritise the four stated needs?, 5) how do we know whether the needs have been addressed satisfactorily? Tool developers should somehow take into account all the issues stated before, so that these tools can be included in the work-flow of architectural offices.

Over the past two decades, the building simulation discipline has matured into a field that offers better methods and tools for building performance evaluation (Hensen & Augenbroe, 2004). The discussion has changed from a focus on the software features to a focus on the effectiveness of the simulation tools, resulting in an emphasis on increasing effectiveness, speed quality assurance and user's productivity and the integration of simulation software with other design applications. Schlueter and Thesseling (2009) claimed that nowadays, still no tools exist which could seamlessly integrate performance assessment into the design process or support the design and decision-making of the architect or building designer. Another important aspect is that holistic performance assessment is not considered in any kind of computer-aided architectural design (CAAD) environment that architects use.

### 2.3.3 Parametric design

Being able to use BPS tools as a design tool would be an ideal situation for architects to design low energy buildings and to see the impact of the implementation of solar energy. Recently several CAAD embedded plug-ins were launched to integrate the simulation tools into the everyday drawing environment of the architect (Table 2.2). Dubois and Horvat (2010) provided an overview of a few of them.

Table 2.2 Overview of available BPS tools as design tools

Sketchup	REVIT	Rhino	Stand-alone
IES VE for Sketchup EnergyPlus for Sketchup	Vasari	Geco (Grasshopper to Ecotect) DIVA for Rhino	Ecotect IES VE

Another trend amongst architects and researchers in architecture is called parametric design; the use of parameters to define a form (Monedero, 1997). In order to research several forms and to see how they comply with predefined goals, the user needs to produce a script which makes this possible. From 2000, there have been several scripting programs available. In some cases, a link with a BPS tool could generate energy performance indicators. An example is the scripting program Grasshopper for Rhino, where the plug-in Geco (Frick & Grabner, 2008) is able to communicate and simulate with the BPS tool Ecotect and return the results back to the CAAD program Rhino.

## 2.4 Design Processes

The EDP in all design processes is often qualified as a vibrant phase. In this early stage, actors need to interact freely to achieve optimal design solutions that eliminate or reduce the need for compromise at a later, more critical period of the process. To enhance the design performance, there is a necessity to develop a working environment that promotes innovative interdisciplinary design (Macmillan, Steele, Austin, Kirby, & Robin, 2001). A lack of shared understanding is one of the causes of poorly organised design teams, which have no real structure or common goal. The study of Macmillan et al. (2001) made clear that design is not only a complex technical process but also a social process. Modern multi-disciplinary design demands that also engineers work in teams; therefore, design methodology has to address the design process as an integration of the technical, cognitive, and social processes.

### 2.4.1 Traditional design process

The design process is different for every architect and project. The majority of architects follows what is called a traditional design process (IEA, 2003). In the traditional design process, the following stages can be distinguished (Jones, 1992):

1. Briefing: statement of user needs;
2. Pre-conceptual design: feasibility study and determination of detailed program requirements;
3. Conceptual design: exploring different schematic design alternatives that agree with the programmatic requirements. This stage is concerned primarily with geometry and orientations, without considering material compositions;
4. Preliminary design: determining material compositions and building details;
5. Detailed design: exploring different detailed design alternatives. This stage deals with the structure and material composition considerations;
6. Design documentation: preparing building documents.

The traditional design process is often characterized by the following features (IEA, 2003): first, the architect and the client agree on a design concept, consisting of a general massing scheme, orientation, fenestration and (usually) the general exterior appearance. Then, the mechanical and electrical engineers are asked to implement the design and to suggest appropriate technical systems. This linear process has proved its value in the last decades, but has not led to optimisation since the design cannot be adjusted to optimise its energy systems. With newer building regulations, technical systems need to be embedded earlier in the design process.

As regards sustainable design, the traditional design process often leads to undesirable design features (IEA, 2003):

- Limited exploitation of the potential advantages offered by solar gain during the heating season, resulting in greater heating demand;
- Possible exposure of the building to high cooling loads during the summer, due to excessive exposure of glazing to summer sun;
- Non-utilisation of a building's daylighting potential, due to a lack of appropriately located or dimensioned glazing, or to a lack of features to channel daylight further into the interior of the building;
- Exposure of occupants to severe discomfort, due to excessive local overheating in spaces facing west or glare in areas lacking adequate shading;
- Lack of computer simulations of predicted energy performance and therefore the resulting poor performance and high operating costs generally come as a surprise to owners, users and operators.

## 2.4.2 Integrated Design Process

The IDP is a relatively new concept and has proven to be more effective in producing high-performance and environmentally-friendly buildings (IEA, 2003). The IDP is a process which considers and optimises the building as an entire system including its technical equipment and surroundings and for the whole lifespan. This can be reached when all actors of the project cooperate across disciplines and agree jointly from the beginning (IEA, 2003). The IDP integrates people, systems, business structures and practices in such a way that it collaboratively reduces waste and optimises efficiency through all phases of design, fabrication and construction (AIA 2007). Both definitions clearly show the focus on collaboration and on a holistic approach to a building. The IDP team needs to be motivated and competent, have clear objectives and the quality of the work delivered by the team needs to be assured throughout the design process.

In general, the IDP will have the following sequence (IEA, 2003):

1. Establish performance targets for a broad range of parameters, and then develop preliminary strategies to achieve these targets;
2. Minimise heating and cooling loads and maximise daylighting potential through orientation, building configuration, an efficient building envelope and careful consideration of amount, type and location of fenestration;
3. Meet these loads by an optimum use of solar and renewable technologies and a use of efficient HVAC systems, while maintaining performance targets for indoor air quality, thermal comfort, illumination levels and noise control;
4. Iterate the process to produce at least two, and preferably three, conceptual design alternatives, using energy simulations as a test of progress, and then select the most promising of these for further development.

The most notable difference with the traditional design process is the role of the architect. While in the traditional design process the architect has the first and most important role and is the initiator of the design chain, in the IDP process, the architect is not the only person making decisions. Architects often retain the guiding function through the position of team leader and moderator. The architect gains knowledge of technical solutions while the engineers are simultaneously gaining insight into the architectural design.



## 3 Literature review

The aim of this chapter is to review important scientific studies carried out within the following subjects: 1) architectural science, 2) integration of solar energy into architecture, 3) design tools, 4) design process, and 5) architectural education. These subjects were chosen because they are all strongly connected to the overall research subject of this study. In total, 45 articles were selected mainly from the databases ScienceDirect (Elsevier, 2012) and Summons (of the library of Lund University). For every subject, different search words were used which are specified in each subsection in this chapter. The search was mainly limited to articles from 2000 or later to get an actual view of the field.

In general, all articles can be classified according to the scheme in Figure 3.1.: field studies, development, and case studies. In the category field studies, the main research method is observations, surveys, and interviews. In the category development, the articles describe newly developed (design) tools or methods. In the category case studies, the articles focus on applied technologies in the built environment.

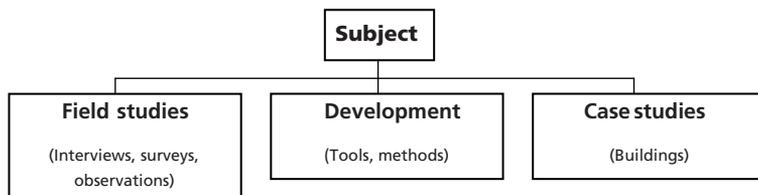


Figure 3.1 Classification of the articles

### 3.1 Architectural science and the design process

In order to get an overview of relevant research conducted on design methods and design research, a search in the databases was performed with

the following key words: DESIGN RESEARCH ARCHITECTURE, and DESIGN METHODS ARCHITECTURE.

Short (2008) claimed that what is understood by architects as research is often not regarded by others as research. Architects consider the practice of architecture as a professional design activity which involves some degree of research, but this definition is not supported by institutional researchers. The research that architects carry out might be considered as applied research, which is defined by the OECD (2002) as ‘an original investigation undertaken to acquire new knowledge. It is, however, directed principally towards a specific practical aim or objective’.

Jones (1992) provided a thorough overview of the field of design methods (in his book ‘Design Methods’). He selected definitions of design, since there is no agreed definition:

- A goal-directed problem-solving activity (Archer 1965);
- Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency (Fielden 1963);
- The optimum solution to the sum of the true needs of a particular set of circumstances (Matchett 1968);
- The imaginative jump from present facts to future possibilities (Page, 1966);
- A conscious effort to design a building which responds to the occupants’ needs, not only physically but also spiritually (Hastings 1989);
- A hybrid activity which depends, for its successful execution, upon a proper blending of art, science and mathematics and is most unlikely to succeed [if only one of these parameters is considered] (Jones, 1992).

Cross (2007) presented an overview of forty years of design research. He has shown that design research has become more and more professional, starting from the first attempts of architectural research in the 1960s until now. He also discussed the themes of design research: people, processes and products. Knowledge about designers (people) can come from empirical studies, knowledge about processes can be obtained from the study of modelling for design purposes (i.e. use of sketches, drawing, virtual reality models), and knowledge about products lies in the forms, and materials.

Yin (2009) described how research on design can be conducted by case-study research; it is the preferred method when (a) “how” or “why” questions are being posed, (b) the investigator has little control over events, and (c) the focus is on a contemporary phenomenon within a real-life context. When knowledge of case studies can be incorporated into a

so-called case-based reasoning system, it could contribute in integrating environmental knowledge in the process of architectural design.

Macmillan et al. (2001) conducted interviews to gain empirical data on design and the design process. The authors stated that the interview as a method for gathering qualitative data has both strengths and weaknesses; one of the flaws is that results can be biased because of the fact that descriptions tend to be over-simplified which represents the interviewee's subjective perception of the procedures rather than the real activities of design that actually took place.

Using interviews and own experiences, Lawson (2006) provided an overview of a very broad field: the design process, design tools, creativity in his book 'How designers think, the design process demystified'. One of the most important issues in this book is the mapping of the design process. Lawson (2006) provided several theoretical models of the design process (Figure 3.2).

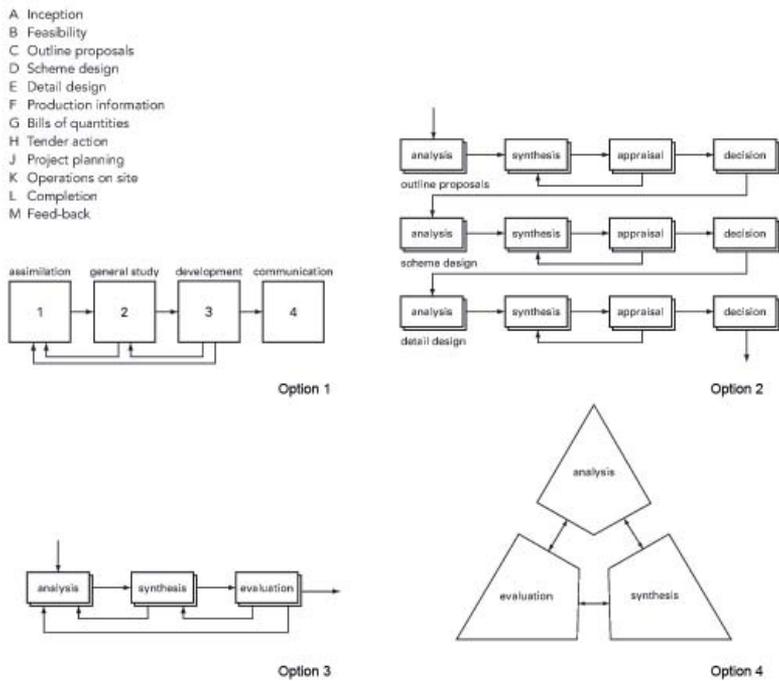


Figure 3.2 Examples of design process maps (Lawson 2006)

Lawson concluded that all these maps are actually both theoretical and prescriptive, and have been set up by thinking about design rather than by experimentally observing it.

Kalay et al. (1998) described that the process of designing, constructing and managing a building is fragmented and involves many participants interacting in complex ways over a prolonged period of time. This collaboration could result in the architects spending more time interacting with other actors rather than actually designing the building. The building needs to be seen as a collective achievement of a diverse team of different disciplines, not as a sole design of the architect. The management of the project team is often in the hands of architects who are not educated for performing this task. With the introduction of BIM, participants are able to exchange more information about the building with each other than before, which should make collaboration easier.

Biesbroek et al. (2010) investigated the design process of Net-Zero Energy Buildings. They found that the currently available software tools and information exchange in the traditional design process have serious shortcomings when Net-Zero Energy Buildings have to be designed and built efficiently. A Business Process Model Notation (BPMN) was used in order to map the design process for a Net-Zero Energy Building (Figure 3.3). Mapping the design process was found necessary in order to identify gaps in the process and shortcomings of the tools used.

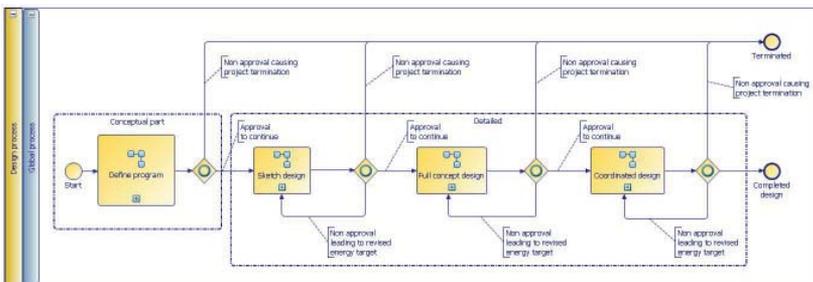


Figure 3.3 Global design process of a Net Zero Energy Building

The EDP was found to be the most important phase to focus on, since decisions taken at this phase have a large impact on the subsequent phases and overall performance of the building. The global design process was divided into four phases; the conceptual part, the sketch design, the full concept design, and the coordinated design. The sub-processes were specified with tasks which have to be performed; these tasks are not assigned to actors but by discipline (e.g. Assignment, Architecture, Building Physics

instead of client, designer, energy analyst). According to the authors, this design map could be seen as a manual for a project team when a Net-Zero Energy Building is designed.

IEA (2000) Task 23 described several case study projects where the IDP has been applied. In many projects, a workshop was the start of the project which stimulated the development of common ideas on the design. An early focus on passive solar strategies was found necessary before active technologies were considered, leading to the right design and system decisions when the costs of changes are still low (Figure 3.4).

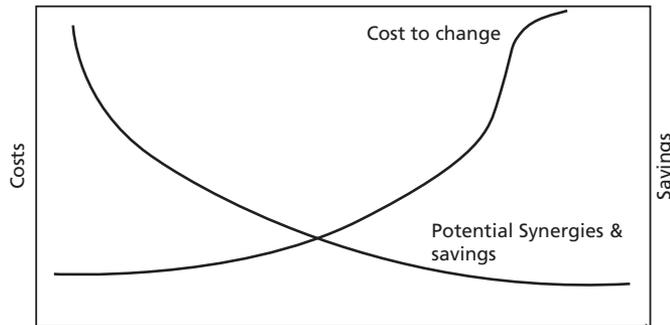


Figure 3.4 Opportunities for change and the design sequence (adapted from IEA 2003)

Another focus point was daylight; if it is taken into account from the beginning, it will create a much better indoor climate.

Lewis (2004) described the IDP and labelled it as ‘crucial for green building’. By following the IDP, buildings are performing better and they are more cost-effective compared with the ones designed according to a traditional design process. The IDP requires a holistic and structured approach including setting targets, working interdisciplinarily and iteratively from the beginning to the detail phase. The author concluded that it is a chance for all actors involved to go beyond their own field while contributing to a common achievement.

Thibaudeau (2008) described several case study projects which all had a high assessment regarding energy use. Different types of buildings were described: hospitals, performance halls, and university buildings. An integrated design approach was found to be necessary in such buildings in order to cover all aspects of the building. By collaboration between different disciplines, and with a willing client, the design process became more efficient.

Brunsgaard (2011) conducted research on passive houses in Denmark. In order to successfully promote passive houses, it was found necessary to have a holistic approach; focusing not only on energy savings, but also on architecture and living comfort. The design process was followed, semi-structured interviews were conducted, and a performance evaluation was performed. The IDP was found to be positive for the design process of passive houses, occupants had to adapt their behaviour when living in such houses, and the indoor comfort was found to be fairly acceptable.

Petersen (2011) studied the design processes of sustainable buildings, by carrying out eight qualitative interviews with professionals, following a case study at an architectural office, and by following students when they were engaged in design. He concluded that previous experiences from other projects are very important and are taken as a base for future design decisions. Furthermore, the communication between the team members was found to be crucial, and digital tools played a very limited role in the EDP.

## 3.2 Solar Integration

The implementation of solar energy into the architecture of buildings has been described mostly by case studies. The search in the databases was performed with the following key words: SOLAR INTEGRATION ARCHITECTURE.

Munari Probst and Roecker (2007) conducted a survey on the architect's perception of the integration quality of Building Integrated Solar Thermal (BIST) systems. The web-based survey was proposed to a large pool of European architects, engineers and facade manufacturers from different climatic European areas; 1500 surveys were distributed, 170 were filled completely. Respondents were asked to rate ten selected examples of existing BISTs using a five-point scale, concentrating on the integration quality, not on the building's architectural value. Results showed a clear ranking of BISTs by architects, and another ranking by engineers. Architects agreed on the value of the integration quality of the objects, engineers and facade manufacturers were generally less demanding regarding integration quality. Some specific system characteristics were highlighted which have an impact on integration quality; e.g. size and position of the collector field, shape and size of the modules, type of joining, collector material and surface texture, absorber colour. Another lesson was that the use of the solar collectors as a construction element was considered to be a good solution when it comes to integration quality.

Hestnes (1999) described several case studies where solar systems became part of the general building design. Eight buildings were discussed, with special focus on the integration of solar systems into the building; place, size, problems of integration, colour and material of solar systems and their architectural features were evaluated. Designers of these buildings should have a good and common understanding of how to design buildings where energy systems are an integral part of the whole, which Hestnes called the holistic approach. Designers needed help when applying this approach in choosing the right solar system. If solar elements replaced other building elements, their architectural integration became better: they served dual functions and thus reduced total costs. Architects have discovered that solar elements can be used to enhance the aesthetic appeal of a building, and their clients have discovered the positive effect of advertising their use of solar energy. In most cases, the key to success in solar building projects was the use by architects of the approach of aesthetic compatibility rather than of invisibility.

Voss (2000) described fourteen demonstration projects initiated in IEA SHC TASK 20 “Solar Energy in Building Renovation”, focusing on the technical, economic, and building physics issues of solar collectors, glazed balconies, and solar walls. The case studies showed that when buildings undergo renovation, solar energy can play an important role in contributing to decreased energy use and in producing energy if it is considered at an early phase. However, solar concepts were rarely discussed in renovation strategies. Solar concepts in renovation can increase comfort and save energy, but were still considered as being too expensive.

Lundgren and Torstensson (2004) investigated the integration of solar energy in buildings in Scandinavia and the Netherlands through the showcase of selected projects. All the involved architects found PV interesting as a building material. In some case study buildings, PV was introduced late in the process, resulting in a less attractive integration compared with those buildings where PVs were integrated from the beginning of the project. Furthermore, architects experienced the financial factors as limiting.

Henemann (2008) described building integrated photovoltaics (BiPV) as an important product which can change the perception of solar energy since they are more attractive and adaptable than regular systems. Some of the advantages mentioned were that the modules can be integrated into non-ventilated facades of new buildings, in ventilated facades to increase the appeal of old buildings; they replace other building materials, can be used as balustrades, and function as a screen against noise, wind, sun, etc.

Kosoric et al. (2011) described the building integration of PV on a demonstration site in Singapore. In the design process, which was divided into three phases, eight design alternatives were created which all had to

be innovative, functional, successfully integrated into the architecture and have a good performance considering both costs and energy output. In design phase 1, suitable places for the PV were selected. In phase 2, design alternatives were generated and optimised, and in phase 3, the eight design alternatives were assessed by multi-criteria decision-making (MCDM) in order to pick the best alternative. The use of such a MCDM method was seen as successful since it reduced subjectivity, but special attention should be devoted to the determination of weighting coefficients.

Davidsson et al. (2012) developed a multifunctional PV/T hybrid solar window, which combined thermal collectors, PV, and sunshades. Although the integration of these elements reduced the total price of the construction and the thermal losses due to insulated reflectors, solar radiation was blocked that would otherwise have contributed to the passive heating of the building, thereby limiting the performance of the solar window. A building with the solar window would use 600 kWh less auxiliary energy than a building with no solar collectors, but when all components were placed on the building separately, the building would use 1100 kWh less auxiliary energy. This study thus showed that the solar window was not that efficient and also blocked the view out and reduced daylight penetration.

Quesada et al. (2012) performed a detailed literature review of solar facades, with a special focus on opaque solar facades. The conclusions of this review were divided into several technologies. BiST is a relatively simple technology, but not yet fully optimised and understood. BiPV have many advantages since they do not only produce energy, but can also reduce cooling loads when the air flow behind the panels is utilised efficiently? Hybrid ST/PV systems were seen as improving the economic return of the system by combining the two technologies. The most developed system is the thermal storage wall or Trombe wall, which reduces the heating load by about 40-50%. They also concluded that the technology of solar chimneys needs to be optimised before they can be used in the best way.

### 3.3 Design Tools

Design tools can be a significant help for architects and other actors in the design process to support decision making regarding solar energy. The search in the databases was performed with the following key words: SOLAR DESIGN TOOLS ARCHITECTURE. Furthermore, conference papers were also considered to be highly useful.

Dubois and Horvat (2010) provided an overview of digital tools used for solar design. The report presented the digital tools according to three categories: 1) CAAD (computer-aided architectural design), 2) visualisa-

tion, 3) simulation tools. A list of the selected programs can be seen in Table 3.1.

Table 3.1 Listed digital tools (Dubois & Horvat 2010)

	CAAD tools	Visualisation tools	Simulation tools
1	Allplan	Artlantis	bSol
2	ArchiCAD	Flamingo	DAYSIM
3	AutoCAD	Kerkythea	DesignBuilder
4	Blender	LightWave	Design Performance Viewer
5	Bricscad	LuxRender	Ecotect
6	Caddie	Maxwell Render	EDG II
7	CATIA	mental ray	EliteCAD
8	CINEMA-4D	POV-ray	ENERGIEplanner
9	DDS-CAD	RenderMan	eQUEST
10	Digital Project	RenderWorks	Green Building Studio
11	form-Z	V-Ray	IDA ICE
12	SketchUp	YafaRay	IES VE
13	Houdini		LESOLAI
14	IntelliPlus Architecturals		Polysun
15	Lightworks		PVSystem
16	Maya		PV*SOL
17	MicroStation		Radiance
18	Revit		RETScreen
19	Rhinoceros 3D		T*sol
20	SolidWorks		VisualDOE
21	Spirit		
22	Vectorworks		
23	3DS Max		

The authors came to the following conclusions: when it comes to visualisation, digital tools were often limited; visualisation software did not provide technical solar calculations but most of these programs were used to study direct and/or diffuse light penetration patterns and shading effects on building facades and inside buildings, at one specific moment or for a sequence in time. Only a few visualisation programs provided numerical output of light intensity results; the focus was clearly on visualisation rather than numerical analysis. A big issue when it comes to visualisation programs was the validity of the generated pictures: it is not always clear whether they were cosmetic or generated according to the law of illumination. The review also showed that most tools were more suited for later (detailed) design phases than for the EDP.

In addition, Horvat et al. (2011) also carried out an international survey on digital tools used by architects for solar design within the framework of IEA-SHC Task 41 Solar Energy and Architecture. The web-based survey focused on identifying current barriers preventing architects from using existing methods and tools for solar building design, and to identify important needs and criteria for new or adapted methods and tools to support architectural design and integration of solar components at the EDP. Results showed that architects did not rate their skills of digital tools as very advanced (Figure 3.5).

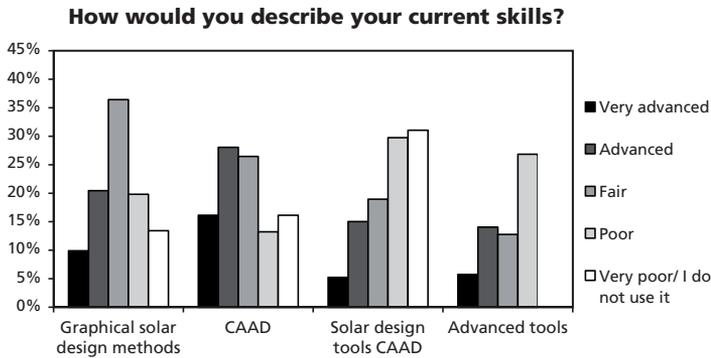


Figure 3.5 Current skills of architects regarding digital tools (Horvat et al. 2011)

Also, the results showed that architects saw a need for improved tools when designing solar integrated architecture. Architects also saw a need for improved tools for visualisation, preliminary sizing and tools providing feedback in the conceptual phase. In the preliminary design phase, respondents mostly saw a need for improved tools for preliminary sizing, tools providing key data and visualisation. In the detailed design phase, results show that respondents need improved tools for providing key data, followed by the need for improved tools for preliminary sizing, visualisation and tools providing explicit feedback. And finally, in the construction drawings phase, most respondents answered that they did not know if they needed improved tools, followed by the need for improved tools for providing key data and preliminary sizing. When respondents were asked to identify the main barriers to the use of tools, results showed that these were the complexity of the tools, costs of tools, lack of integration with CAAD software and the high time consumption –almost all factors identified by respondents earlier when choosing their software.

De Wilde and van der Voorden (2004) studied three office buildings in the Netherlands, in order to assess the current situation regarding the selection and implementation of energy saving building components and the role of computational tools in supporting this selection. The results of the case-studies indicated that 1) selection of most energy saving building components took place during conceptual design, 2) selection of most energy saving building components took place based on the use of these components by architects or consultants in earlier projects, 3) there was no selection of energy saving building components based on an equivalent comparison of the performance of several design variants, 4) building simulation tools were used after the phase of conceptual design was finished. A survey following the case studies was sent to architects and consultants who had been involved in the design of energy-efficient buildings in the Netherlands. The survey validated the case-study research: 1) most energy saving building components were selected without computations, but based on earlier experiences, 2) most of the energy saving building components were selected without considering alternatives.

Attia et al. (2009) conducted a survey amongst architects in order to compare several BPS tools for their 'architect-friendliness'. The authors mentioned that most of the current users of those BPS tools were researchers and experts, not architects. The architect-friendliness was judged upon two factors: usability and information management of the interface, and the integration of intelligent design knowledge-base. Ten BPS tools were compared: Ecotect, HEED, Energy 10, DesignBuilder, eQUEST, DOE-2, Green Building Studio, IES VE, EnergyPlus, and EnergyPlus for Sketchup (OpenStudio). The results of the survey made it possible to divide the BPS tools into three categories. The first category was found to be most architect-friendly and included the following software: IES VE, HEED, and eQuest. The second category was less architect-friendly and included the programs Ecotect, DesignBuilder, Green Building Studio, and Energy 10. The third category had the lowest architect-friendliness and included EnergyPlus for SketchUp, EnergyPlus, and DOE-2. According to the authors, a design tool for an architect should educate as well as inform the architect on the assumptions underlying the results.

### Tools on building scale

Meniru et al. (2003) performed a protocol study in order to understand architects' needs for a new tool which would make it possible to reduce the complexity of the design process. The protocol study was divided into an interview (15 min) and a design session (45 min), and was videotaped. Eight architects were asked to design a residence on a piece of land. The interviews consisted of a mixture of structured and open questions and

the formulation of the questions was based on their goal to develop an early computer design tool. In the design session, designers were asked to provide a design solution as they would normally do, while speaking out their thought aloud. The results showed that in the design process, there are four main activities usually performed in sequence –design brief, site preparation, building space and building elements. These activities require different design capabilities and types of interactions. With all the information obtained by the protocol, the authors expressed the wish to develop a computer tool for the EDP, but this has not been accomplished yet.

Ellis and Matthews (2001) developed a new simplified thermal design tool designed to fit the architect's design methodology. The goal of the tool was to reduce the input complexity without having to simplify the thermal building model, featuring a new ranking evaluation method that enables architects to quickly compare different variations. The necessity of this development can be explained by the fact that when it comes to tools for architects, the architects' needs for a tool could be specified as follows: 1) the tool should be user-friendly and easy to use, 2) input formats must be user-oriented and expressed in terms of building materials rather than thermal properties, 3) solutions must be obtained quickly, in minutes rather than hours and 4) it should be able to handle 'what if' alternatives, 5) the social component of the tool should not be overlooked (e.g. how is the computer tool embedded in the company culture), and 6) the tool should be validated, and 7) tools incorporating a financial element are more likely to succeed. Furthermore, tools that overwhelm the architects with the amount of input data or knowledge required will not be used.

Yeziro (2009) described a new simulation tool (PASYS), which provided design guidelines and procedural methods for determining which passive systems suit the local climatic conditions best. The reason for the development of this program was the fact that most available design tools focus on the whole design process, not on stages of it. The first design stage is the manual design tool, which gives design guidelines about general size required for solar systems, but lacks the accurate treatment of local climatic conditions. The second type is a CAD system. Advanced computer tools are available for the more detailed design phase and only manual tools are available for the EDP, while in this stage, major measures for improving the energy performance are most powerful.

Chela et al. (2009) developed a new methodology that simplified parametric studies during the design process. According to these authors, the main advantage of using their method was to reduce the number of numerical simulations needed to get as much information as possible and thus reduce time. The authors also stated that the design of a low energy building has to take into account all the requirements regarding the environmental impact, indoor thermal comfort and indoor air quality,

investment costs etc, something which could be done through simulation tools, but this is a time-consuming activity. Their Design of Experiments (DOE) method was designed to simplify the parametric study. However, the DOE method may also present significant experimental errors because of the complexity of the modelled output. So called meta-models evaluated the energy demand and the final energy use of the building, which could replace the simulation tools to perform low energy building design.

Petersen and Svendsen (2010) developed a new method and simulation program for making informed decisions in the early stages of building design to fulfil performance requirements regarding energy consumption and indoor environment. The development of this new method came after the observation that most tools were not suitable for the evaluation of design alternatives in the EDP. The proposed new method is in the form of a simulation program (iDbuild), focusing on generating design advice regarding energy performance and the quality of indoor environment.

Garde et al (2010) described the PERENE project, the aim of which is to help design low energy buildings in French territories. The PERENE 2009 methodology consists of the following steps; 1) definition of a climatic zone, 2) determination of a typical year for each zone, 3) building design –application of simple rules of thumb, 4) energy efficiency of systems, 5) assessment of the building, 6) feedback. Step 3 is the most interesting and important step for architects; it provides general recommendations, rules of thumb on how to design solar shading, outer walls, sizes of windows and openings etc. Following these steps will give architects a series of possibilities regarding the way to design as energy efficiently as possible on Reunion Island.

### Tools on urban scale

Gadsden (2003) mentioned the lack of tools that can help city planners to make informed decisions concerning solar energy. In order to bridge this gap, the author set up a system, which was designed to be used for the three key solar technologies: passive design, solar thermal and photovoltaic systems. The developed system was based on a GIS-system and took into account several passive design elements such as orientation, overshadowing of the main glazed facade, the urban horizon angle (average angle of elevation from the centre of the affected surface to the top of the obstruction), ratio of glazing area on the main facade to that on the other facades, and glazing type. By predicting energy consumption and comparing it to the potential energy production of PV and ST, the system was able to inform city planners when they were making decisions in the design process.

Compagnon (2004) also presented a method to quantify the potential of facades and roofs located in urban areas for active and passive solar

heating, PV electricity production and daylighting. The sky model was simplified, and the 3D geometry was only modelled by their enclosing envelope to reduce the amount of data. The sky and 3D building geometry were then processed using the Radiance simulation software which works with a backward ray-tracing method. The output of the simulations provided the fractions of the total facade or roof area that are appropriate for various kinds of solar energy techniques. According to Compagnon, this method provided the opportunity to make quantitative comparisons between urban planning proposals concerning irradiation levels, which are exemplified in Figure 3.6.

Urban area	View	Plan	Orientation rose	Facades annual irradiation per square meter floor area ( $kWh/m^2$ )	Potential for passive solar heating techniques (%)	Potential for photovoltaic systems (%)	Potential for daylighting systems (%)	Potential for solar thermal collectors (%)
Whole area (present situation) plot ratio = 1.2				224	32	6.5	54	50
Stripes (10 storeys) plot ratio = 2.0				309	52	21	82	70
Comb (six storeys) plot ratio = 2.0				251	49	21	68	69
Courtyard (six storeys) plot ratio = 2.0				215	37	16	69	67
Stepped slab blocks (five and eight storeys) plot ratio = 2.0				290	52	17	85	82

The analysis is performed on the buildings within the dotted outlines. The potential values are calculated for facades only. For each column, the maximal value is indicated in bold.

Figure 3.6 Comparison of four hypothetical urban forms (Compagnon 2004)

Ratti et al. (2005) described the effects of urban texture on building energy use by buildings, based on the analysis of digital elevation models (DEM). The authors claimed that the effect of urban geometry on energy use is understudied and controversial, and one of the reasons for this is that modelling urban geometry is too complex. To avoid problematic and difficult calculations, a digital elevation model (DEM) stored urban 3D information using a 2D matrix of elevation values. By using this DEM, energy use could be obtained through simulation. One type of analysis can be, for example, an obstruction sky view (OSV) analysis, which indicates critical point in the urban fabric.

Cheng et al. (2006) examined the relationship between built forms, density and solar potential by means of three design criteria: openness at

ground level, the daylight factor on the building facade and the PV potential on the building envelope. The simulation program PPF was used to perform the calculations. The solar potential for photovoltaic systems (PV) was defined as the percentage of the building envelope which received an amount of solar radiation greater than or equal to the preset thresholds. This definition can be an interesting numerical goal of implementing solar energy into urban planning. It is however important to define this threshold for every country, since several conditions –annual solar radiation, costs, energy network- are the base for this threshold. Based on the three parameters, the authors gave recommendations on how solar energy can be implemented in urban planning.

Hoferka and Kanuk (2009) presented a methodology for the assessment of photovoltaic potential in urban areas using open-source solar radiation tools and a 3D city model implemented in a GIS system. In this case, the open-source program r.sun was used, combined with the PVGIS estimation utility. This method used a three-step procedure to assess the PV potential in urban areas: 1) the creation of a 3D city model implemented in a GIS model, 2) solar radiation modelling including the analysis of spatial and temporal variation in solar irradiance/irradiation using the r.sun solar radiation model, and 3) calculation of potential electricity production using the PVGIS estimation utility with parameters derived from a GIS database. Results showed that the largest PV potential had been found in urban zones with large buildings with large, free roof areas and that the most effective buildings in terms of annual electricity production per footprint area were blocks of flats.

Kämpf and Robinson (2010) described a new methodology for optimising building and urban geometric forms for the utilisation of solar radiation. Their methodology was based upon a hybrid algorithm and the ray tracing program Radiance, and applied to a three dimensional urban geometry. To avoid complicated simulations by introducing too many parameters, the authors used optimisation algorithms. With three examples, they demonstrated their program, which provided a visual output of maximum solar radiation, and which could serve as an underlying design tool for architects and urban planners.

Okeil (2010) developed a new model for the evaluation of the relationship between urban built form and energy efficiency in order to provide city planners with tools to help make informed decisions. The basic scale of study was the urban block scale. The new model is compared to two older well-known urban planning principles, that of linear strokes and (closed) blocks on the percentage of daily direct solar radiation (Figure 3.7). Results show that the new model allowed the maximum potential of passive utilisation of solar energy in buildings, and combined this high solar exposure with the functional, spatial, social and visual advantages.

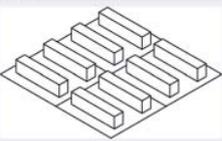
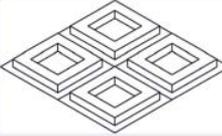
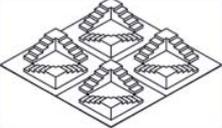
Module parameters	Layout (2 × 2 modules)
<p>Urban form: linear</p> <p>Module size: 76.8 m × 76.8 m                      Building length: 60 m                      Building height: 15 m                      Street width: 26.4 m, 16.8 m                      Foot print/module: 1440 m<sup>2</sup>                      Surface area/volume: 0.28</p> <p>Total area: 5898 m<sup>2</sup>                      Building width: 12 m                      Court: 60 m × 26.4 m                      Orientation: 0°, 45°, 90°                      Floor area ratio: 1.2</p>	
<p>Urban form: block</p> <p>module size: 76.8 m × 76.8 m                      Building length: 60 m                      Building height: 9 m                      Street width: 16.8 m                      Foot print/module: 2304 m<sup>2</sup>                      Surface area/volume: 0.2</p> <p>Total area: 5898 m<sup>2</sup>                      Building width: 12 m                      Court: 36 m × 36 m                      Orientation: 0°, 45°                      Floor area ratio: 1.17</p>	
<p>Urban form: RSB</p> <p>Module size: 76.8 m × 76.8 m                      Building length: 60 m                      Building height: 3–15 m                      Street width: 16.8 m                      Foot print/module: 1840 m<sup>2</sup>                      Surface area/volume: 0.31</p> <p>Total area: 5898 m<sup>2</sup>                      Building width: 12 m                      Court: 36 m × 36 m                      Orientation: 45°                      Floor area ratio: 1.1</p>	

Figure 3.7 Main parameters of urban forms studied for incident solar radiation (Okeil 2010)

In the thesis of Montavon (2010) entitled ‘optimisation of Urban Form by the Evaluation of the Solar Potential’, actual and theoretical urban forms were compared in order to explore the diverse effect of daylighting and solar potential on dense sites. In this study, sites in Switzerland and Brazil were analysed, as well as Le Corbusier’s Contemporary City of Three Million Inhabitants. Simulations were made with Radiance and PPF. A very extensive literature review described general rules about solar energy in urban planning from the very beginning of urban planning and the current scientific models and computer tools about this subject. An issue which was already discussed in the early days (and still is today) is the choice between various solar orientations. Factors that influence the implementation of solar energy into urban planning are: financial aspects, environmental aspects, energy-efficiency of buildings, comfort, ambience, and protection. Montavon also noted that with today’s construction techniques and software, all kinds of complex shapes can be built to such an extent that energy-efficiency comes to play a secondary role. In the simulations made for different cases mainly in Switzerland, thresholds were specified to compute the potential contribution to solar energy (see Table 3.2).

Table 3.2 Thresholds for several active solar systems (Montavon 2010)

Solar technology	Threshold for systems mounted on facade	Threshold for systems mounted on roofs
Photovoltaic systems	800 kWh/m <sup>2</sup> /year	1000 kWh/m <sup>2</sup> /year
Solar Thermal collectors	400 kWh/m <sup>2</sup> /year	600 kWh/m <sup>2</sup> /year
Passive thermal heating	Varies according to climates; the amount of solar irradiation required to fully compensate for the heat loss through a standard double-glazed window during the heating season for Basel (Switzerland)	

Montavon (2010) defined the concept of solar potential as a metric, defined here as the percentage of the building envelope area that is lit by an irradiation or an illuminance larger or equal to the corresponding thresholds, similar to the definition used by Cheng et al. (2006). In the case of the Mattheus district in Basel (Switzerland), the distribution of the threshold and the solar potential can be seen in Figure 3.8.

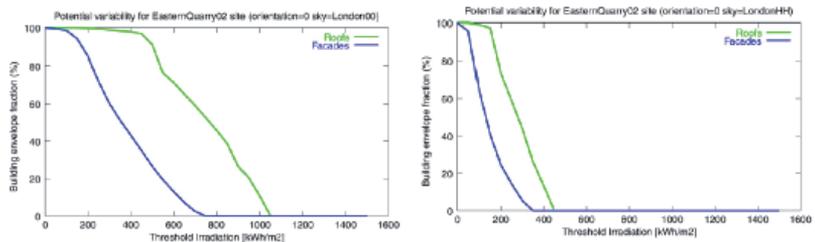


Figure 3.8 Cumulative distribution characterising the building envelope's solar irradiation (Montavon 2010). On the left, the potential for building integrated PV systems and ST collectors, on the right the potential for passive solar heating techniques.

The main findings of Montavon (2010) are summarised below:

- It is necessary to take all orientations into account to improve the viability of solar technologies;
- Implementing PV panels on facades in a dense urban area might not be that viable;
- Reorganising the layout of building blocks (without reducing the usable floor area) allows achievement of considerable progress in terms of daylight and solar potential.

Van Esch et al. (2012) discussed the effects of urban and building design parameters on solar access and solar heat gain. Buildings with three different roof shapes and two different orientations were simulated in order to see the effect on the two parameters. The results showed that the street width had a significant influence on the global radiation of the canyon: the wider the street, the higher the global radiation yield. Increasing the street width was also preferable from the point of view of maximising the solar gain of dwellings in the winter. Decreasing the street width would result in limiting overheating in summer as well as increasing density in cities. Maximising solar exposure of the building envelope in the winter can best be done in the east-west street direction, since the radiation yield of dwellings in east-west canyons is larger in winter compared with north-south streets. For canyons in east-west direction, single-pitched roofs produced the highest yield. Increasing the amount of transparent facade openings will not always improve the solar performance of the dwelling and will often lead to overheating in summer. The authors concluded with a discussion about what urban and architectural design is preferable for both indoor and outdoor conditions.

Ibara and Reinhart (2011) compared six different distribution methods of solar irradiation. The six methods were: 1) Daysim DS, 2) Daysim DDS-s, 3) GenCumulativeSky, 4) Ecotect tiles, 5) Ecotect Points, and 6) a manual method in Excel. Two test cases were compared with each other; in one case, measured data was compared with the six different methods, and the second case represented a tower in a complex surrounding urban fabric. In case 1, where the measured data was taken as a reference, the biggest relative errors were made on the north side with the manual calculation in Excel and with Ecotect Points (Tables 3.3 and 3.4).

Table 3.3 Absolute and relative errors for annual irradiation for all simulation methods (case 1, where measured data was taken as a reference)

Distribution Method	North		East		South		West		Horizontal	
	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]
Measured Data	234	reference	584	reference	798	reference	562	reference	1162	reference
Excel	98	<b>41.9</b>	-76	<b>-13.1</b>	-37	-4.6	107	19.0	-144	<b>-12.4</b>
Ecotect Points	112	<b>47.7</b>	42	<b>7.2</b>	68	<b>8.5</b>	23	4.2	-52	-4.5
Ecotect Tiles	44	<b>18.9</b>	6	1.0	-83	<b>-10.4</b>	-70	<b>-12.4</b>	-62	<b>-5.3</b>
GenCumulativeSky	-2	-0.8	10	1.8	30	3.7	34	6.1	-9	-0.8
Daysim-DS	-12	<b>-5.0</b>	-22	-3.8	-6	-0.8	-11	-1.9	-61	<b>-5.3</b>
Daysim DDS-s	-18	<b>-7.8</b>	-31	<b>-5.4</b>	-12	-1.6	-11	-1.9	-58	<b>-5.0</b>

In case 2, the Daysim program was taken as a reference. Compared with Daysim, the biggest relative errors were seen, on average, with the Ecotect Tiles method.

Table 3.4 Absolute and relative errors for South annual irradiation for all simulation methods by elevation (case 2, where DaySim was taken a reference )

Distribution Method	2.0m		100m		220m	
	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]	Absolute Error [kWh/m <sup>2</sup> ]	Relative Error [%]
Daysim DS	489	reference	727	reference	1086	reference
Ecotect Points full res	-23	-4.7%	-68	-9.3%	-59	-5.5%
Ecotect Tiles full res	-169	-34.5%	-249	-34.3%	-176	-16.2%
GenCumulativeSky	17	3.4%	-35	-4.8%	-41	-3.8%
Daysim DDS -s	-3	-0.5%	-10	-1.4%	-7	-0.7%

The results in this study have shown that Radiance-based programs made the smallest relative errors under these conditions. Furthermore, the authors demonstrated that differences in results between the different methods significantly influence the design recommendations.

Jakubiec and Reinhart (2011) developed DIVA 2.0; a sustainability analysis plug-in for the Rhinoceros 3D modelling program, making use of Radiance / Daysim, and EnergyPlus. In the EDP, detailed geometric building models were often made for visualisations. DIVA was integrated as a plug-in in the CAAD program where these models were made, which makes it easier to perform daylight analyses already in the EDP. Output of the simulations can be either numerical or graphical. Combining the trusted simulation methods Daysim and EnergyPlus within a popular environment where architects model their geometry, might be a step forward for performing energy and daylight calculations in an EDP. However, the program is currently limited to one thermal zone.

### 3.4 Architectural Education

Embedding sustainability within the curriculum of the schools of architecture is a very important strategy to build up knowledge amongst newly educated architecture students. The search in the databases was performed with the following key words: ARCHITECTURE SOLAR ENERGY EDUCATION.

Hamza and Horne (2007) described the proposal of the embedding of low energy architecture courses and projects in the curriculum of the School of Built Environment in Northumbria, UK and its evaluation. The proposed methodology aimed to provide students with a practical approach in which they would be able to assess the impact of their own decisions on energy use. Observations showed that students were interested in apply-

ing the know-how of using software and observing the impact of changes on their own designs. A survey was conducted to evaluate the introduced courses and projects. Almost all students agreed that the integrated project had helped them understand the process of achieving a low energy building and furthermore the courses allowed students to see all three factors of designing, visualising and environmental simulation together. When asked about the disadvantages, results show that students experienced a heavier workload as an important disadvantage.

Knudstrup et al. (2009) described a student project at the University of Aalborg, Denmark. The student project was embedded in an engineering degree which addresses the professional gap between architectural and engineering degrees, and exemplifies how future housing can help to take care of the environment in a sustainable way. Architectural and engineering strategies towards sustainability were described and they stated that the following design principles are generally associated with the issue of achieving and avoiding external heat gains in temperate climates: 1) window areas and orientation, 2) seasonal shade, 3) insulation of the building envelope, 4) minimising and avoiding thermal bridges, 5) surface to floor ratio of the building shape, 6) airtightness of the building envelope, 7) ventilation strategy, 8) zoning.

Poerschke (2007) described the experiences of a course on sustainable architecture at the Pennsylvania State University. The major principle of this course was to link the technical, aesthetic and social approaches of sustainable architecture in such a way that they became integrated. The project was studio-integrated to have the student's full attention and to give the opportunity to apply gained knowledge on an architectural project. Within the current curriculum of architecture students, some technical courses were already incorporated and given by both engineers and architects. The methodology within the course consisted of four steps; 1) the students were introduced to the theory about the conceptual approach of sustainable architecture, 2) a systematic overview of passive and active strategies was presented, 3) a hierarchy of environmentally responsible strategies was presented, and 4) the students were taught that environmental thinking takes place on different scales. According to the authors, the main outcomes of the course were the intensive student involvement in issues of environmental sensitivity and the understanding that environmental strategies must evolve out of a strong overall concept.

Dunay et al. (2006) described the setup of a collaboration between the Virginia Polytechnic Institute, industry, and practice. This institute joined the Solar Decathlon, a competition to design and build an energy-efficient house powered solely by the sun. A multidisciplinary group worked together from the beginning of the design process. Fifty student groups were assembled and the brief for the solar powered house was conducted

through a research course. The group members were from various backgrounds: architecture, industrial and interior design, and mechanical and electrical engineering students. Seven teams were selected and were asked to elaborate about material selection, energy collection systems, conservation strategies, and transportation. In the end, one project was chosen which best fitted the brief and had the best energy performance. All the involved students worked with industry and this resulted in the development of new building elements.



## 4 The interviews

The main research method in this study of architects' design process in solar integrated architecture has been the semi-structured interview. Section 4.1 briefly reviews how this research has been embedded in the qualitative research tradition, 4.2 describes the interview procedure, and 4.3 describes the results of the interviews.

### 4.1 Qualitative research methods

In general, research can be defined either as quantitative or qualitative. There is also a combined approach that has several names: multi-method, multi-strategy, mixed-methods or mixed-methodology (Bryman, 2008). Qualitative research uses a naturalistic approach that seeks to understand phenomena in context-specific settings (Hoepfl, 1997). Another definition of qualitative research is given by Strauss and Corbin (1990): 'qualitative research means any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification'. In contrast, quantitative research uses experimental methods and measures to test hypothetical generalisations (Hoepfl, 1997). Mixed-mode is the combination of qualitative and quantitative research.

The quantitative and qualitative approaches correspond to different paradigms (Hoepfl, 1997): quantitative researchers seek causal determination, prediction, and generalisation of findings while qualitative researchers seek illumination, understanding, and extrapolation to similar situations. According to Bryman (2008), qualitative research is often seen as a research strategy with an emphasis on an open-ended approach to research.

Corbin and Strauss (1990) described that the research question should dictate the methodological approach. Qualitative research can be used to better understand any phenomenon about which little is known and to gain new perspectives on things about which much is already known, or to gain more in-depth information that may be difficult to gather in a quantitative way. On the other hand, qualitative methods are found to be more appropriate in situations where variables first need to be iden-

tified which might later be tested quantitatively, or where the researcher has determined that quantitative measures cannot adequately describe or interpret a situation (Hoepfl, 1997). Qualitative research has a diversified source of data collection including interviews, observations, videos, documents, drawings, diaries, memoirs, newspapers, biographies, historical documents, autobiographies etc. (Corbin & Strauss, 1990).

### Semi-structured Interviews

In order to obtain data about the process of the architect when designing solar integrated projects, the interview was chosen as the most practical data collection method. In this case, by means of qualitative research, it was possible to register a process. It also provided the opportunity to explore more in depth with the architects, keeping the results of IEA SHC Task 41's international survey (Horvat et al., 2011) in mind.

Patton (1990) distinguished three types of qualitative interviews: 1) informal, open-ended interviews, 2) semi-structured interviews, and 3) standardised, open-ended interviews. In this research project, the method of semi-structured interviews was chosen because it gives interviewees a certain freedom to express their ideas, and responses can be analysed in greater depth (Horton, Macve, & Struyven, 2004). The interviews were accompanied by an interview guide: a list of questions or general topics that the interviewer wants to explore during each interview. Similar research carried out shows that this research method has been tested before in the field of architectural research (Johnson, 2005; Pamela, 1991; Portillo & Dohr, 1994; Saeema, 2005; Tomes, Oates, & Armstrong, 1998; Wong, 2010; Yasemin, 2011). Furthermore, earlier research has shown that it is possible to draw conclusions from a limited amount of case studies (Flyvbjerg, 2006; Ruddin, 2006).

### Analysis

Hoepfl (1997) defined qualitative data analysis as working with data, organising it, breaking it into manageable units, synthesising it, searching for patterns, discovering what is important and what is to be learned, and deciding what to tell others. Corbin and Strauss (1997) defined analysis as an action that involves examining a substance and its components in order to determine their properties and functions, then using the acquired knowledge to draw conclusions about the whole. According to Altinay and Paraskevas (2008), qualitative analysis is the conceptual interpretation of the dataset as a whole, using specific analytical strategies to convert the raw data into a logical description and explanation of the phenomenon under study.

Analytical tools can be very useful to study and organise the gathered data. Those analytical tools will help analysts to 1) distance themselves from literature and personal experiences that might block objectivity and the capacity to see new possibilities in data, 2) avoid standard ways of thinking about phenomena, 3) stimulate the inductive process, 4) avoid taking anything for granted, 5) allow for clarification of assumptions that researchers and participants make (Corbin and Strauss, 1997).

## 4.2 Interview Procedure

### Interview guide

The goal of the interviews was to gain insight into the design processes of Scandinavian architects and urban planners involved in solar architecture and urban plans. It was expected that the situation in the three countries Denmark, Norway, and Sweden would be rather similar, since they have more or less the same installed solar capacity, except for the low installed ST capacity in Norway (Weiss and Mauthner 2011) (Table 4.1). However, it was known that the architectural culture, political climate and building industry would differ slightly between the three countries.

Table 4.1 Installed capacities in Denmark, Norway, and Sweden (International Energy Agency 2011, Weiss and Mauthner 2011)

Country	Total capacity of Solar Thermal in operation by the end of 2009 [ $MW_{th}$ ]	Installed PV power capacity at the end of 2010 (MW)
Denmark	356,5	7,1
Norway	11,6	9,1
Sweden	290,5	11,4

Furthermore, it might be useful to give an overview of the current building regulations regarding energy demands in the three countries (Table 4.2).

Table 4.2 Energy demands of new buildings include the heating, cooling, ventilation and DHW in Denmark, Norway, and Sweden

**Danish Building Regulations 2011 (Energistyrelsen, 2011)**

Houses, hotels etc.	Offices, schools
52,5 kWh/m <sup>2</sup> year + + 1600 kWh/ living area	71,3 kWh/m <sup>2</sup> year + + 1650 kWh/ living area

**Norwegian Building Regulations 2010 (Direktoratet for byggkvalitet, 2011)**

Single-family houses	Apartment	Commercial
120 kWh/m <sup>2</sup> year + 1600 kWh/living area	115 kWh/m <sup>2</sup> year + 1600 kWh/ living area	150 kWh/m <sup>2</sup> year + 1600 kWh/ living area

**Swedish Building Regulations 2011 (Boverket, 2011)** (values for three climatic zones)

Houses		Commercial buildings	
Without electric heating	With electric heating	Without electric heating	With electric heating
130 / 110 / 90 kWh/m <sup>2</sup> year	95 / 75 / 55 kWh/m <sup>2</sup> year	120 / 100 / 80 kWh/m <sup>2</sup> year	95 / 75 / 55 kWh/m <sup>2</sup> year

Before selecting appropriate architecture offices, an interview guide was set up to serve as a basis for all the interviews (Table 4.3) and was developed in cooperation with members of the IEA SHC Task41: Solar Energy and Architecture. The interview guide for the urban planners (Table 4.4) was almost similar, but was obviously focused on urban planning instead of buildings. Both interview guides were developed in English and later, if necessary, translated into Swedish.

The interview guide and questions were set up to make sure that all aspects of the projects were taken into account and to highlight all problems, barriers and framework of the implementation of solar energy into architecture. The first question was asked to make sure that different terms, like solar integrated architecture and active solar technologies, were clear both for the interviewees and the interviewer.

Table 4.3 Interview guide for architects

<b>Introduction</b>	<b>Design process</b>	<b>Lessons learnt and barriers</b>
<p><b>Question 1</b> What is solar integrated architecture for you and do you think it is an important aspect of sustainable design?</p>	<p><b>Question 3</b> Could you describe the early design phase for this project? What was done and what was the role of the participants?</p>	<p><b>Question 6</b> How did you gain the skills that you presently have with the tools and solar</p>
<p><b>Competences</b></p> <p><b>Question 2</b> What basic information and/or knowledge should an architect have before starting to design a project like this?</p>	<p><b>Question 4</b> Could you describe the rest of the design process in phases?</p> <p><b>Question 5</b> Which design tools did you use during the design process and how useful did you find these tools?</p>	<p><b>Question 7</b> What are your lessons learned in this project and how is this project different from other projects done by your office?</p> <p><b>Question 8</b> According to you, what are the most important barriers to exploiting solar energy as an architect?</p>

Table 4.4 Interview guide for urban planners

Introduction	Design Tools	Lessons learnt and barriers
<p><b>Question 1</b> What is solar integrated urban planning for you and how does it relate to other parameters in urban planning?</p>	<p><b>Question 4</b> What design tools did you use during the design process? Who used these tools?</p>	<p><b>Question 6</b> What are your lessons learned in this project and how is this project different from other projects?</p>
<p><b>Design process</b></p> <p><b>Question 2</b> Could you describe the design process? What was done and what was the role of the participants?</p> <p><b>Question 3</b> How do you ensure that architecture takes care of solar energy in a later phase?</p>	<p><b>Question 5</b> If you could imagine the perfect design tool for solar integrated urban planning, what would it look like?</p>	<p><b>Question 7</b> According to you, what are the most important barriers to exploiting solar energy as an architect?</p>

In order to test the interview guide, a pilot interview was conducted with an architect in Malmö, Sweden. After this pilot interview, only the introduction was changed according to the recommendations of the interviewed architect. The main questions were not changed because they seemed to provide a good framework.

### Selection of offices

After the final determination of the layout of the interview guide, architecture offices in Denmark, Norway and Sweden were selected. Architects were selected for participation when their office had designed (and preferably built) a solar building. Another factor in the selection was that several building types were represented in the sample –commercial, residential buildings and even some larger scale projects. Additionally, two local urban planners were also interviewed in order to highlight barriers in solar integrated urban planning.

In Table 4.5, an overview is provided of the projects and their status of completion. Some of the projects were under construction at the time of the interview.

Table 4.5 Overview of projects

Type of project		Completion	
Residential	8	Completed	11
Commercial	5	Not completed	12
Public	6		
Urban plan at architecture office	2		
Urban plan at planning department	2		

All selected architects and urban planners were contacted by email and phone, and all of them agreed to participate. The architects received the questions prior to the interviews so that they could prepare for it. In general, the interviews lasted between 30–60 minutes, depending on the motivation and availability of the architect. All interviews took place at the office of the architects and were tape-recorded. The interviews in Sweden were held in Swedish, while all interviews in Denmark and Norway were held in English. A short introduction was given by the interviewer in order to explain why this interview was important and how data would be treated. It was also made clear that personal information would be treated carefully and that it would not be published.

After the interviews were conducted, the transcriptions were written, and if needed, translated and transcribed. The grounded theory of Glaser and Strauss (1967) was chosen as the main qualitative research method since it provides researchers with a concrete working methodology to process raw data to theory and generalisation. The different stages in the process are described in Table 4.6. The steps provided in the grounded theory (Bryman, 2008) were followed in order to structure the data and treat all interviews equally.

Table 4.6 Tools of grounded theory (Bryman 2008)

Stage	Purpose
Coding	<i>Data is broken down into components, and given names</i>
Theoretical saturation	<i>Reaching a point where new data are no longer illuminating</i>
Constant comparison	<i>Process of maintaining a close connection between data and conceptualisation so that the correspondence between concepts and data is not lost.</i>

In order to analyse and code such a large amount of data, the program QSR NVIVO 7 (QSR-International, 2006) was used (Figure 4.1). In the program, categories were defined before the analysis was initiated and were mainly derived from the interview guide. These categories were 1) concept of sustainable and solar integrated architecture, 2) competences of architects –which competences are needed and how to gain them?, 3) design process of the specific projects –early consideration, teamwork, design tools, communication with the other actors, 4) barriers to implementing solar energy. It was expected that with the creation of these four categories, all areas of the interviews were covered. After coding, the categories were exported to a word processing program.

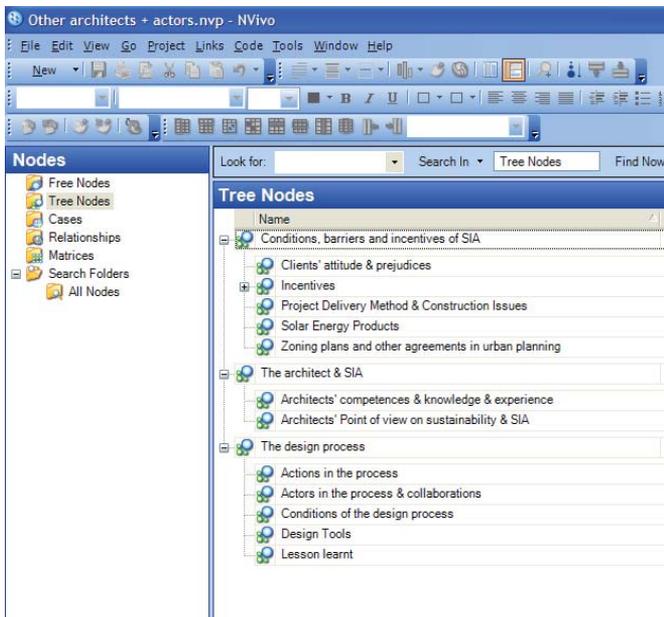


Figure 4.1 The program NVivo 7 is a tool to process raw data into categories

## Sample

The 23 interviews were carried out between December 2010 and November 2011 in the cities of Aarhus (DK), Copenhagen (DK), Gothenburg (SE), Karlskrona (SE), Lund (SE), Malmö (SE), Oslo (N), and Stockholm (SE). Figure 4.2 provides an overview of the different locations.



Figure 4.2 Location of the interviews

The majority of the interviewees (8 females, 15 males) had more than ten years of experience. Some interviewees were also sustainability coordinators of the office. In one case, the interviewee was an industrial PhD student, i.e. a PhD student working half time at the university and half time at an architectural office. The interviewed urban planners were also educated as architects and gained experience at the department of urban planning. As regards the size of the architectural offices and the separate urban planning departments, four of the offices had one to five employees, five had five to ten employees, seven had ten to 50 employees, and seven had more than 50 employees.

### 4.3 The results of the interviews

The large body of transcribed text was divided into the following categories:

- Concept of sustainable and solar integrated architecture;
- Competences of architects –which competences are needed and how to gain them?;
- Design process of the specific projects –early consideration, teamwork, design tools, communication with the other actors;
- Barriers to implementing solar energy.

The subsections of section 4.3. are presented according to these categories.

### 4.3.1 Sustainable and solar integrated architecture

The architects were asked to provide their definition of sustainable architecture in order to see which elements they found important. Even though all interviewed architects defined sustainable architecture in a unique way, there were several components which were often mentioned (Figure 4.3).

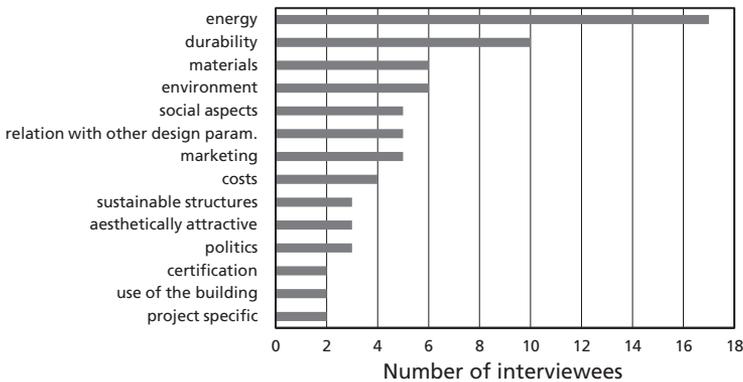


Figure 4.3 Mentioned components in architects' definition of sustainability

Interestingly, some architects saw sustainable architecture as a unique selling point, while others mentioned that it had turned into a superficial buzz word.

*'We see it as something everybody wants to be. It is like saying that you are creative. Who doesn't want to be creative? But now [for us] it is just something we just do along with all the other professional requirements. It is not that interesting anymore' (architect #17)*  
*'We are all almost fed up with the word and the term' (architect #20)*

It was expected that architects would see solar energy -in all its aspects- as an important part of sustainable architecture, something which was mentioned by a few architects. Some of them did not experience this connection so clearly and saw solar energy as just one of the many design parameters. Likewise, the urban planners also felt very clearly that solar energy was just one of the many parameters.

*'I cannot say [how important solar energy is compared to all other parameters in urban planning] exactly. I have to be honest and say that it is very far down' (urban planner #2)*

In the urban planning projects, interviewees expressed that dense cities are in conflict with the solar integrated city, since access to solar energy gets limited in denser cities.

When the subject was solar integrated architecture, there was a noticeable difference of approach between the countries. In Sweden, most of the architects mentioned first the active utilisation of solar energy by means of solar cells and solar panels, and secondly they mentioned the passive utilisation. In Denmark, almost all architects mentioned first the passive utilisation of solar energy –mostly daylight and passive heating- before mentioning the active utilisation.

*'Solar energy [for] producing energy is not so important for us. But how we orient the building and how we configure the whole building is based on our knowledge of daylight' (architect #19)*

Many architects talked about the risk of overheating in the building. When buildings are getting more insulated, the risk for overheating increases, even in the periods which were normally not seen as sensitive (autumn, spring and even winter) in the Scandinavian countries. Furthermore, architects expressed their concern that with increasing regulations on the indoor climate, buildings will get a larger cooling demand if they get overheated more often and will thus use more energy; a consequence which was obviously undesirable from the architects' point of view. As a consequence, many architects expressed the necessity of having proper solar shading systems, preferably combined with active solar technology to produce energy. In almost none of the projects was a 'standard' solar shading system incorporated. Solar shading devices were often custom-made; designed and developed in order to fit into the building's architecture.

Another interesting issue which was taken up by several architects when solar integrated architecture was discussed was the significant focus on technology in their projects. Motion-controlled ventilation and lighting systems, and computer-controlled solar shading systems were seen as limitations on the users' ability to control their working and living environment, either when the system was running or when –for some reason- it would shut down. Some architects felt it as their duty to protect the users' ability to control their living and working environment.

### 4.3.2 Competences of architects

The interviewed architects were asked what competences were required to design solar integrated architecture. It was expected that this question could indicate a possible barrier: a lack of knowledge amongst architects.

One architect mentioned that solar energy had both an architectural and a technical component; it touched all important elements of architecture –facades, materials, the layout of the building-, but it also required more technical knowledge about the implementation of solar energy into buildings. Several other architects expressed that it is the architect's task to know a little about a wide array; in order to make a building more coherent with all its components. Solar energy is in this regard only considered as one of many parameters in the design of a building.

Almost all architects confirmed that an increased technical knowledge was necessary to design solar integrated architecture and that their own knowledge level was too low, but interestingly, there was a big conceptual difference in how high this level of technical knowledge should be for an architect. Many architects expressed that the need of increasing their technical knowledge was relatively new since stricter building regulations have put much emphasis on energy issues.

#### Organisation of offices

The reason for acquiring an increased level of technical knowledge and competence was mainly found to be twofold:

1. It would give architects the opportunity to make informed design decisions (a process called by several architects as evidence-based design)
2. Architects could have a better dialogue with engineers.

In general, architecture offices responded in two ways to compensate for their lack of technical knowledge: either they train their own architects and / or employ more engineers to form an in-house source of technical knowledge, or they set up a close collaboration with external engineers. Interestingly, it was more common in Denmark to develop technical knowledge in-house, while in Sweden, it was more common to collaborate with engineers. Furthermore, developing this technical knowledge was seen as costly for a small office or undesirable since it was considered by some architects to be too far outside the field of architecture. Another important issue was that of responsibility; according to many architects, it is the engineers who are educated in this area and they should be those responsible for all technical input in the design process. Another way of working was that architects took decisions on design alternatives in the

EDP, but the final and legal responsibility was still in the hands of engineers, corresponding to a more traditional approach. In the case of urban planning, collaborations were set up with larger consortia of engineering firms, institutions (e.g. universities) and other consultants.

An alternative situation was found in two Danish architectural offices, where industrial PhD students were working half-time in the architectural office and half-time in the Academy of Architecture. These PhD students supported the design process and provided project architects with design tools.

### Needed technical competences

The majority of the interviewed architects expressed their uncertainty about what basic knowledge was needed regarding the implementation of solar energy into architecture. A general overview of available solar technologies and other systems was seen by almost all architects as necessary. More specifically, some architects mentioned that knowledge of the following components would provide a better integration of solar energy into buildings:

- local climate conditions:
  - o solar access,
  - o temperature,
  - o surrounding buildings.
- requirements for active solar systems:
  - o optimal local inclination,
  - o optimal azimuth,
  - o needed components and their space requirements (e.g. accumulator tank),
  - o energy output,
  - o dimensions of the panels.
- costs of the systems;
- conditions of feeding in overproduction into the grid;
- internal loads;
- other technical systems (e.g. type of ventilation system);
- construction methods, e.g. airtightness.

Obviously, it was expressed by many architects that they should be competent in transforming this knowledge into usable input in the design process. Only one architect mentioned that architects should know what design tools would fit the design process best.

How to develop the necessary competences?

Many of the architects experienced that gaining and / or developing this new technical knowledge was difficult, and this was also true for the urban planners. The architects stated that it was hard to be updated because of the rapid technical development of solar technologies.

*'Basically, you have to update yourself all the time. You become very dependent on technology and the technology changes all the time'*  
(architect #11)

The range of sources for gaining knowledge mentioned by the architects was diversified:

- 'Learning by doing',
- Working with engineers,
- Study trips,
- Internal courses,
- Conferences, workshops and literature.

The first source 'learning by doing' was mentioned by all architects and it reflects the basic idea of the architectural profession: an architect learns and develops knowledge by doing / making / designing / testing several design alternatives. Several architects did not have any experience in solar integrated architecture before starting the project but by going through the design process of such a project, they were confronted with the problems and possibilities of the integration of solar energy into buildings.

*'I had never seen a solar cell before I started this project, except for the one on my calculator'* (architect #3)

By working together with engineers, architects experienced an important knowledge transfer. Despite some difficulties in the collaboration, the majority of architects did appreciate this kind of knowledge transfer, especially when the collaboration lasted throughout the whole design process.

Study trips were seen by many architects as a perfect way of gaining knowledge, because they enable the participants to experience themselves how solar energy was integrated. By seeing different examples of integration, architects can judge for themselves how several systems and applications work and look, which could be vital information when new buildings are designed. Visiting case studies was also seen by some architects as an ideal way of showing clients that solar integrated architecture has been achieved before in an aesthetically attractive way.

*‘That’s why it is (...) important to have good examples; (...) to experience it yourself, to have evidence that it is done. This works and it looks damn good.’ (architect #4)*

In order to educate many architects at the same time, architecture offices chose sometimes to create internal lectures or workshops by inviting speakers. Other sources were attending conferences and workshops, and by reading literature. Many architects considered the national building regulations also as literature.

#### Architectural education

The subject of architectural education was not always discussed in the interviews. Several architects had the opinion that it was legitimate that the current architectural education focused on the fundamental elements of architecture and aesthetics because they are hard to learn afterwards. These architects experienced that it was easier to gain technical knowledge afterwards than aesthetic values.

*‘There are a lot of people you can just call and ask [regarding solar energy products]; ‘How big is the tank? How much insulation do we need?’ There is no one you can call and ask ‘is it nice or ugly with this roof angle?’ You have to learn that in school’ (architect #2)*

Other architects had the opinion that newly graduated architecture students did not have adequate technical knowledge.

Besides the issue of technical knowledge, one architect also stated that the architectural education hardly focuses on the design process itself. With new, more complex, design processes like the IDP, it becomes important for the architect to be able to communicate well with the other actors.

### 4.3.3 The design process

Of all the 23 different projects, 19 projects were buildings. The building type (residential, commercial, public) as well as the building scale differed significantly. It was expected that this mix, as well as the mix of size of architectural offices, would give a richer image of the design process. This subsection provides the highlights and summarises important points and elements from all these processes.

#### Early consideration

In the majority of the discussed projects, architects were commissioned by the clients (mostly real estate developers) to design a building. In other

cases, architects were invited for a competition, or they participated themselves in a competition.

In many cases, clients commissioned architects directly because of the well-known profile of the architectural office, i.e. an experience with low energy buildings. In almost all design processes, the client expressed clearly an emphasis on low energy use. In the cases prior to or in the early 2000s, this emphasis was almost never converted into clear, measurable goals like desired energy use per year, or achieving a certain building assessment (like LEED, BREEAM). This is simply due to the lack of such building assessment systems at that time or the lack of tools to simulate how much energy a building would use. With stricter building regulations and the introduction of building assessment systems, the energy use of buildings started to have an increasingly large impact on design decisions in the design process. An overview of the defined goals from the beginning of the design process (note that only buildings are taken into account) is presented in Table 4.7. The overview shows that in ten projects a non-measurable goal was defined (like ‘the building needs to be sustainable’). All the other projects had an extra set of requirements which were stricter than the current building regulations. Architects experienced that clients are becoming increasingly interested in building assessment systems, which will often lead to higher initial investments. However, they mentioned that building certifications were seen by the clients as a marketing instrument to increase the value of the property.

Table 4.7 Defined goals of buildings at the beginning of the design process.

	Goals of the building	
International	LEED	0
	BREEAM	0
	Passive house	1
	European Energy Class (A)	1
National	Swedish Green Building	1
	Danish Building Regulations 2015	2
	Swedish Environmental Program South	2
	Energy Class (Sweden)	1
	CO <sub>2</sub> -neutral Building	1
	Non-measurable goal (>current building regulations)	10

Interestingly, two often used international building assessment systems (LEED and BREEAM) were not used as certification systems in any of the

building projects. Clients chose to comply with future building regulations, especially in Denmark. That means that buildings constructed in e.g. 2005 did not only comply with the current (and legally binding) building regulations of 2005, but clients wanted buildings to comply with the building regulations of 2015, which were already published. In Sweden, a wide range of assessment systems were used. Legal conditions could also vary from location to location. In some of the Swedish cities, like Malmö, the municipality sold pieces of land if property owners did comply with stricter requirements than the current building regulations.

### Teamwork

The participating architects were asked to qualify their design process. In the projects designed prior to or in the early 2000s, architects admitted that their process was more traditional, but with the difference that engineers were involved a bit earlier in the design process. Practically, this meant that the engineer was not a core member of the design team in the EDP, but functioned more as a consultant for the design team (mostly architects). Because of this, the influence of the engineers was limited.

In the later projects, many architects said their design process was an IDP, and they mentioned that their process was iterative rather than linear (Figure 4.4).

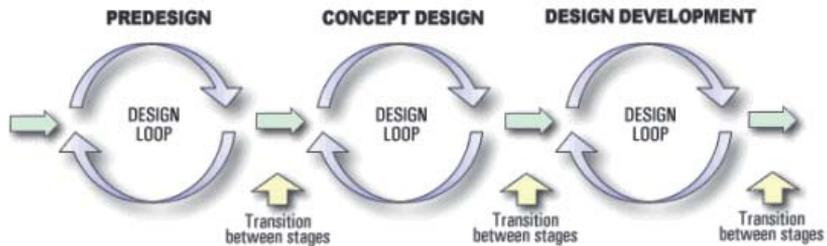


Figure 4.4 The IDP (IEA 2003)

The architects who qualified their process as IDP mentioned the early involvement of the engineers as a clear indication. However, there was a difference to be seen in the way architects described how the (external) engineers were involved. In some cases, engineers functioned as consultants and were only consulted sometimes in the pre-design phase, but mostly, the architects made the drawings and handed them to the engineers who performed calculations. Other architects described a deeper involvement

of engineers in the EDP; the engineer was described as part of the design team. In the majority of cases, an external engineer was involved.

The collaboration was often achieved by having workshops at the very beginning of the design process, where mainly architects and engineers worked together for a certain amount of time. During these workshops, the goal was to reach an early design of a building with a common agreement by the whole design team. Not only was the architectural design specified, but also the technical system of the building, in order to reach a low energy building. In some architectural offices, the technical competence was available in-house, resulting in an acceleration of the collaboration between architects and engineers, since communication was easy.

The development of the architectural design went often hand-in-hand with the technical design; if changes were made to the architectural design, the consequences on the technical systems were evaluated, and vice versa. In this iterative way, it led to compromises for both parties but to a building on which all parties agreed.

*'We [the architect and the building services engineer] sat down and sketched together. I think that this is usually the fastest way to [do;] that a person says something about a system that fits together [with the project]. And if it is like this, then you start to discover which consequences it has for the building. If it has [non-desirable] consequences, then you ask... is there another system that we can have as well? But we also proposed solutions the engineers didn't think of.'* (architect #8)

The majority of the architects found the collaboration with engineers crucial and very important, mainly in designing middle- to large scale solar integrated buildings. Architects often experienced the collaboration as positive since they learned much from it. However, the collaboration was not always flawless: architects found that engineers 'spoke another language', were often 'too specialised', and 'not willing to compromise on certain issues'.

*'The engineer was pretty categorical and technical and (...) "engineering". You could get mad at him as an architect. He didn't think like an architect.'* (architect #7)

*'[during a conversation between the architect and the engineer about solar cells, the engineer says] 'it has to be this angle and in this direction', but then we as architects sketch and say: 'we want this angle and this direction because it looks better'. Then the engineers perform calculations and then they see that there was not much of a difference. That is the [kind of] dialogue you want to have'* (architect #5)

Interestingly, in some cases, the architects followed the engineer's advice and point of view without questioning. In other cases, architects sometimes questioned the engineers and proposed to do something else. In one design process, engineers outnumbered the architects, leading to the architect's realisation that architects also need to be technically competent in order not to become overshadowed by the engineers.

The design process can be seen as a chain of design decisions; several design alternatives are proposed, evaluated, and the most appropriate one chosen. It had been common that design alternatives were only evaluated on the basis of aesthetic and organisational reasons. Now, with stricter building regulations, design alternatives were also evaluated on their energy performance. Architects wanted to compare different design alternatives relatively, not absolutely. This means that design alternatives were compared on a better / worse performance, not on the amount of kWh. This evaluation method was described by the architects as fact-based design or evidence-based design.

### Integration of active solar systems

The role of solar energy in the building was almost never specified; in some cases the client wanted to show PV and ST as a pedagogical example or as a marketing tool; making people aware that the building was producing energy as well. In only one case did the client set a measurable goal: the building needed to have net-zero energy use. In order to reach that, solar cells were implemented both on roofs and facades in order to generate as much energy as possible. Interestingly, in the case of many competitions, solar cells were part of the design in the competition phase, but were abandoned later in the design process because they were found to be too expensive in the client's view. In Denmark, many architects said to have focussed on reducing the building's energy use, and that current building regulations do not require the remaining energy to be produced locally or by renewables.

In the urban planning projects, solar energy was always mentioned as an important contributor to the production of local energy, but it was never specified in a measurable way. What was done by the urban planners was a qualitative assessment of solar energy, focusing on daylight and shading in the public spaces. The urban planners explained that they did not perform a quantitative analysis since they did not have the tools for that and lacked competence to perform such calculations.

Visibility of the active solar components, PV as well as ST, was a clear issue in the design processes. The client did not always want solar components to be visible and they ended up out of sight on the roof. This was mostly due to resistance by the clients to active solar components for

aesthetic reasons. However, another group of clients clearly saw the marketing value of active solar components and prioritised these components to be in visible places. This decision sometimes implied that PV or ST was put in places which did not have the best conditions.

In general, the interviewed architects considered active solar components as interesting components to work with in the building design. Furthermore, architects found that if active solar components were abandoned during the design process by the client, it was outside their power to achieve solar integrated architecture.

### Integration of passive solar strategies

The passive elements of solar energy –heat and daylight- were mainly considered by the Danish architects as the most important elements of solar integrated architecture. The integration of these passive elements was found to have a large impact on the architecture of a building; affecting e.g. the placing of windows, the thickness of outer walls etc. In several design processes, design alternatives were also evaluated by simulating the daylight performance of design alternatives.

Overheating was clearly found to be an important element of passive solar energy. Some architects wanted to block the sun in the summer to prevent the building from becoming overheated and at the same time produce energy by using PV or ST. In one case, the architect integrated a ‘glass chimney’, which blocked the sun in the summer and produced electricity at the same time.

In order to prevent buildings becoming overheated, design teams had to incorporate a solar shading system. The necessity of incorporating such a system was often taken up by the engineers since it did not always occur to the architects. Architects had got used to the fact that whole glazed facades were possible. However, stricter building regulation nowadays almost makes it impossible to have such buildings. Current solar shading systems were often considered not to be aesthetically attractive, which resulted in custom-made solutions in many buildings. Blocking solar rays by introducing fins into the shell of the building was often seen as one solution of incorporating such solar shading (Figure 4.5), even though this solution might actually create greater energy losses in the winter than savings in the summer.



Figure 4.5 *Fins blocking incoming solar rays*

### Design tools

It was important to see how architects worked with design tools. The term design tool was meant here to be any tool which supported the design team during the design process. In the interviews, there was an emphasis on three important design tools: Computer Aided Architectural Design (CAAD) tools, visualisation tools, and BPS tools. Many architects were uncertain how to interpret the term design tool, because they said not to have used any design tool during the design process.

Interestingly, many architects, especially in Sweden, summed up design tools which they called traditional: hand drawings, physical models, 2-D and 3-D CAAD drawings. In the majority of the design processes, Building Information Modelling (BIM) had not been used, which could be mainly due to the fact that it is quite a recent development in the building industry, and many discussed buildings were from before the breakthrough of this development. BIM was used only in more recent, large-scale projects. Within the urban planning process, urban planners mentioned that they did not use any specific quantitative tools, but used the program Google SketchUp to look qualitatively at daylight and solar access of public spaces.

Concerning the implementation of solar energy and energy issues in general, architects mentioned that they used rules of thumbs, BPS tools,

or consulted an (external) engineer. There was a noticeable difference between the countries with respect to the use of BPS tools. In Norway and Sweden, hardly any architect used BPS tools themselves but relied on rules of thumb and / or consultation with an engineer. In Denmark, many architects were using BPS tools themselves, but engineers were still involved. In Figure 4.6, an overview of the design tools used by the architects is provided.

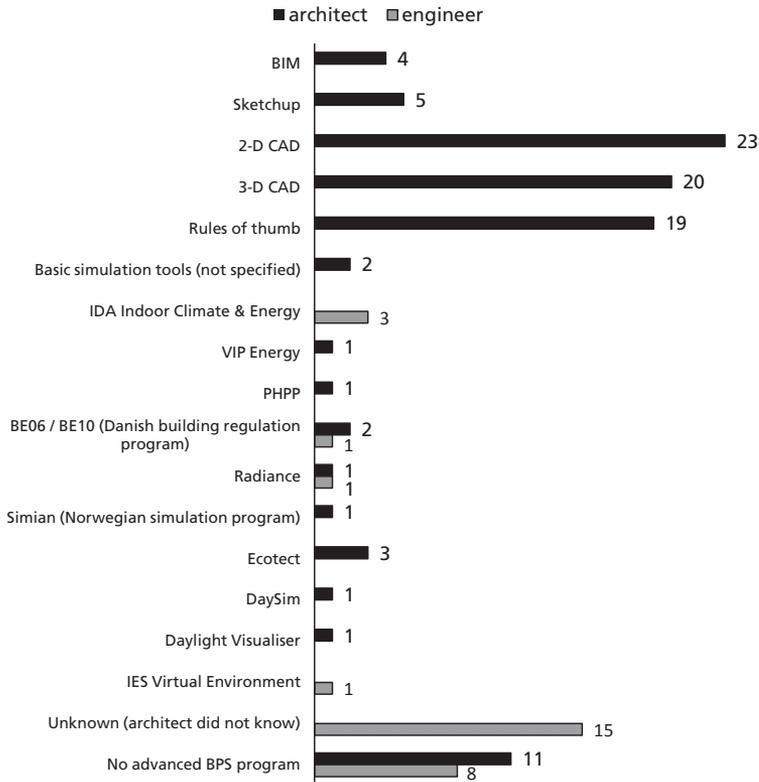


Figure 4.6 Design tools used during the design process

Rules of thumb still seemed to be a well used tool by architects, especially in the EDP, because they provide a quick estimation of several parameters. An example of such a rule of thumb can be seen in Figure 4.7 (Solelprogrammet, 2012).

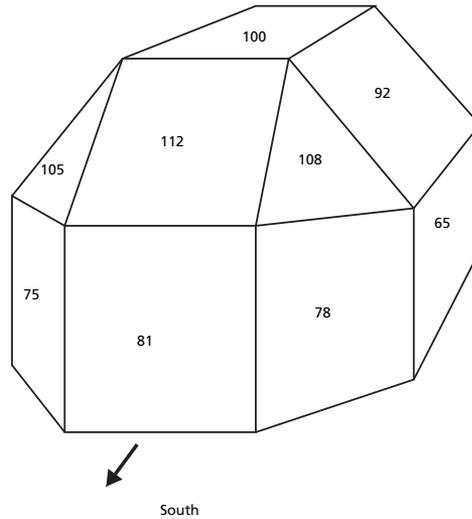


Figure 4.7 Solar radiation in per cent on different inclined and orientated surfaces (adapted from Solelprogrammet 2012)

Rules of thumb were often used to provide an estimation of the window area, thickness of outer walls, annual solar radiation, appropriate inclination of active solar components, and dimensions of systems.

In the design processes of the projects prior to or in the early 2000s, no advanced BPS tools were used, simply because they could only be handled by experts and they did not integrate well into the architects' work flow. In the projects designed later, i.e. between 2000-2011, BPS tools were used more often. There was a big difference in handling BPS tools in the design processes. One group of architects did not use BPS tools, mostly because they found it to be outside the architect's responsibility to perform such simulations. Other complicating factors were the costs of the software and the education of employees. It was for these reasons that many architects worked together with engineers because they were considered to have more knowledge about such programs. Interestingly, many architects were not able to name the BPS tools used by the engineers.

Another group of architects did use BPS tools themselves in order to support the design process, especially in Denmark. During the design process, different design alternatives were evaluated with BPS tools, often in order to evaluate design alternatives in relative terms (worse or better energy performance) rather than absolutely (i.e. a certain energy use by the building). Simulating the absolute energy performance of the

building was still in hands of engineers who had the legal responsibility for the outcomes. In such a way, the Danish (and one Swedish) architects were able to validate more design alternatives and provide feedback much faster to the design team, instead of waiting for an external engineer to perform a similar simulation. This is directly linked to the difference in how building regulations are implemented. In Sweden and Norway, it is necessary to perform energy calculations, but it is not necessary to use a specific computer program. In Denmark, it is compulsory to use a specific computer program in order to obtain a building permit; the latest one which is currently used is BE10 (Statens Byggeforskningsinstitut, 2012). Even though this program is a relatively standard BPS program, architects who are using it can compare design alternatives with each other.

In one case, a new method of design was used during the design process. An involved industrial PhD student had developed a facade by parametric design; a method to generate a design by defining parameters in a computer program. An advantage is that processes could be achieved much faster and more precisely compared with manual calculations and design.

The architects who used BPS tools themselves found that they needed to run several BPS tools in order to deal with all aspects of solar integrated architecture. Many aspects required stand-alone tools, like thermal, solar access, and daylight calculations. Architects mentioned that it would be helpful if programs could be combined, since it takes too much time to import geometries and properties in different programs.

The urban planners expressed that it would be useful to have a BPS tool that would be able to quantify the contribution of solar energy in a specific urban plan. This is interesting, since such tools do exist, e.g. Autodesk Ecotect (Autodesk, 2011) and IES VE (IES, 2010), but it seems that the architects were unaware of that.

### Communication with the client

Several architects found that they were responsible for showing how much active solar energy could contribute to the energy balance of the building. These architects provided an overview of investment costs and benefits for the clients for implementing active solar systems in the buildings. However, they found that this was a rather poorly developed skill amongst architects. Only a few architects were able to provide a clear and visual overview of the impact of energy related decisions on the architecture. The example which can be seen in Figure 4.8 provides a roadmap towards lower energy use; what choices have to be made to reach such levels and how much will these choices influence the architecture of the building.

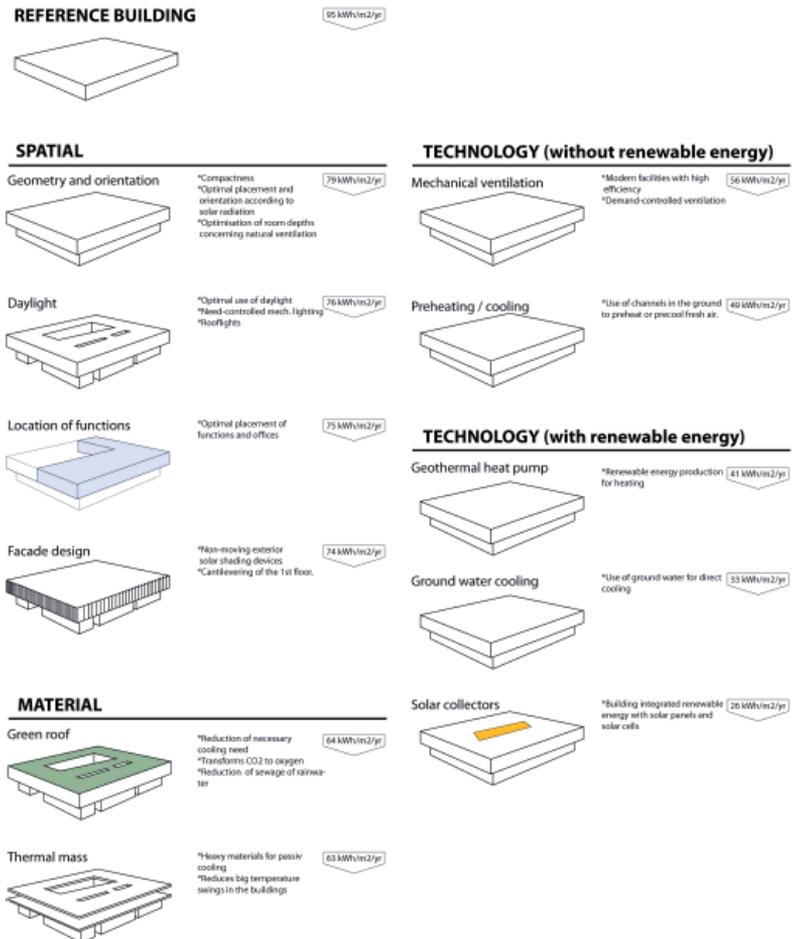


Figure 4.8 Consequences of different design parameters on the energy use of buildings (adapted from Henning Larsen Architects, 2011)

#### 4.3.4 Barriers to implementing solar energy

The interviewed architects were asked to identify barriers to implementing solar energy into architecture. The majority mentioned financial issues as the biggest barrier.

##### Investment costs

The high price and relatively long payback time were mentioned as the most important barrier to implementing solar energy into architecture

and urban projects. However, not all architects found active solar energy products expensive; it was mostly the client who found these too expensive. The financial barrier is a complex problem and was considered to be outside the architects' control. Underlying problems for abandoning the implementation of solar energy in the form of active solar products were discussed by the architects, and these were mainly the relatively long payback time and unfavourable local conditions (lack of subsidies and / or feed-in-tariffs).

In many design processes, active solar energy technologies were integrated in the architecture of the building at the very EDP. Also in the cases of competitions in which sustainability was the winning factor, many proposals had integrated solar cells, but were abandoned later in the design process. Obviously, the client's will was here decisive; clients who 'believed' in solar energy were willing to invest in it and were planning to maintain the building in the long term. Other clients which were more sceptical often abandoned solar energy. Many architects mentioned that there was a culture amongst some clients to focus only on a short term payback time and not on owning and maintaining the building in the long run. Such a precondition makes it very hard for active solar technologies since they do not have a very short payback time. Clients who had the intention to own and maintain the building for a long time were often more willing to include active solar systems. Some architects were very keen on implementing active solar technologies and performed not only energy calculations, but provided also a financial overview of investment costs and payback times in order to persuade the client.

Abandoning the implementation of active solar technologies on financial grounds was often seen by the architects as disappointing and raised the question of how well clients were informed. Architects wondered if clients were taking into account the latest prices (since prices dropped significantly in recent years). Also, architects themselves found it hard to keep updated with the latest financial developments in this field. It was also unclear for the architects which actors in the design process are responsible for providing an overview of benefits and costs.

Swedish architects identified subsidies as a factor which could speed up the implementation of solar energy in buildings. The Swedish government has a programme where (future) building owners planning to implement solar cells can register in order to get a subsidy for the investment costs. Right now, the architects identified that system as unsatisfactory and unclear. Architects found through their clients that there is not enough money available and that there is a long queue.

## The physical and financial connection to the energy grid

Another very important issue which was taken up for discussion by many architects were the national conditions of the energy grid. In Sweden, some architects argued that 'net metering' should be introduced; a system which deducts the energy outflow from the energy inflow in a building. It has proved to be an efficient way to jumpstart the implementation in e.g. the U.S.A. (Darghouth, Barbose, & Wisser, 2011). In that way, Swedish architects thought it would speed up the implementation of solar energy. The system of net metering has existed for a long time in Denmark (1992), but only one architect mentioned this. The Norwegian architects did not discuss this subject.

The method of net metering is close to another concept which architects discussed in the interviews: feed-in tariff. A system of feed-in tariffs consists of an obligation for utilities to purchase, at a set price, the electricity generated by any renewable energy resource (Rowlands, 2005).

Many Swedish architects mentioned that Sweden should introduce such a feed-in-tariff, and mentioned mostly Germany as a good example for such laws. The Danish and Norwegian architects did not mention this issue.

The two discussed concepts will only work when buildings are connected to an energy network which makes it possible to exchange energy –both import and export- in an efficient way. A so-called 'smart-grid' was discussed in the cases of the urban planning. A smart grid is a grid which is able to balance energy flows with each other and is seen as a necessary instrument for the market penetration of renewables (Wolsink, 2012).

## Building assessment methods

Many architects had experienced a push amongst clients towards low energy architecture and the implementation of active solar technology because of building assessment methods (BAM). Clients wanted to get their buildings to comply with the BAM requirements. BAMs can of course mean different things to different actors (Cole, 1998). Here, in most cases, clients wanted to use BAMs for economic reasons. Interestingly, there was a difference between the countries. In Sweden and Norway, clients were interested in international BAMs like the Green Building certificate and European Energy Class, while in Denmark, clients relied more on Danish BAMs.

*'What I have noticed sometimes was that a client took a decision that was not economically advantageous, (but) that they can put [the costs] on their marketing account' (architect #6)*

Another important point, besides the certificate of the BAM, was the fact that low energy projects started to serve as an example, which attracted a lot of visitors. This was seen as good for architectural offices and clients.

#### Active solar products

The majority of the interviewed architects felt that the choice of attractive active solar products was limited, although many architects mentioned the recent leap forward in the development within this field. Because of this rapid development, it was a general understanding amongst architects and clients that the efficiency of especially PV would increase significantly in the near future. This was in some cases a reason for the client to postpone the decision to implement active solar technologies, because the client had the feeling that they might have outdated technology as soon as it is installed. One architect made the comparison with the rapid development within the mobile phone industry, where one is waiting for the new model to be released and not buying the current model.

Regarding the current active solar products, the architects expressed that they would like to be able to change their size, colour and shape. Most architects would like to see solar products to be fully integrated by replacing materials, not by adding them on top of the building envelope. The current offer of products which fulfil these wishes was found to be very limited at this moment. Architects mentioned that they would like to work with solar products as a building material and not as products so that the building integration would be easier.

# 5 Towards a working method for the implementation of solar energy into buildings in the urban context

Previous steps in the research have indicated that it is necessary to give architects and urban planners information about ways to assess solar energy as parameters in the design process. The theoretical framework (Chapter 2), the literature review (Chapter 3), and the interviews (Chapter 4) have provided valuable knowledge upon which working method for architects and urban planners can be developed. This method will be suitable when working with solar energy on all scales, going from urban planning to the scale of detailing. In the first steps towards this working method, a parametric study was performed to see how different simulation programs can be used to assess the solar potential of buildings in urban environments. Following this experience, the preliminary working method is applied in a test case.

## 5.1 Parametric study

Integration of solar energy on the building level, with roofs and facades as the most logical places to harvest solar energy, needs to be considered carefully because it will affect the architecture and urban environment significantly. In order to support urban planners and architects in their design process and to quantify the contribution from solar energy as a renewable energy source, a parametric study was carried out with different types of urban blocks and their potential contribution to locally produced energy.

### 5.1.1 Method of parametric study

This parametric study consisted of a series of four urban blocks, each with a different design (A, B, C, D). In order to see the impact of density in urban plans, the Floor Space Index (FSI) or Plot Ratio of the urban blocks ranged from 1-5 (Figure 5.1). The plot ratio is the total covered area on all floors of all buildings on a certain plot divided by the area of the plot.

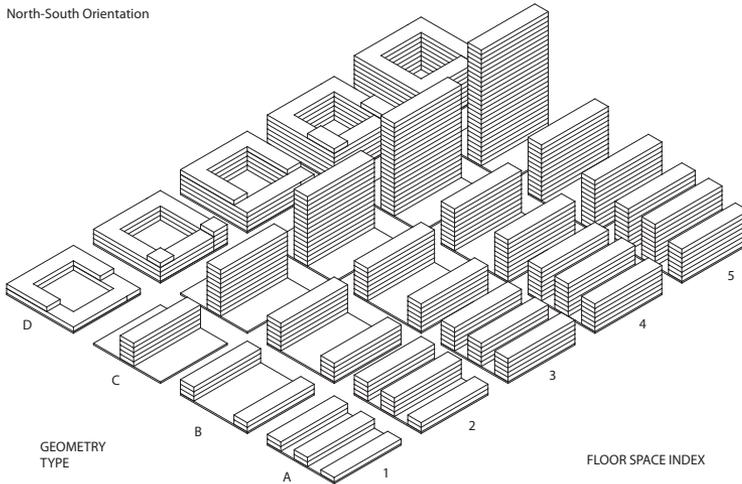


Figure 5.1 Overview of geometry types in North-South orientation

Besides the change of design and density of the blocks, the orientation and environment were also changed. First, the blocks were simulated in North-South (NS) direction, then in East-West (EW) direction. In the third case, the blocks were placed in the North-South direction surrounded by buildings of the same density (Cluster or CL) (Figure 5.2). Building blocks were given a name according to their configuration: NS for North-South orientation, EW for East-West orientation, CL for the cluster orientation. The number corresponds to the FSI, followed by a letter for the design A, B, C or D. NS1A means the building block orientated North-South, FSI is 1, design is option C.

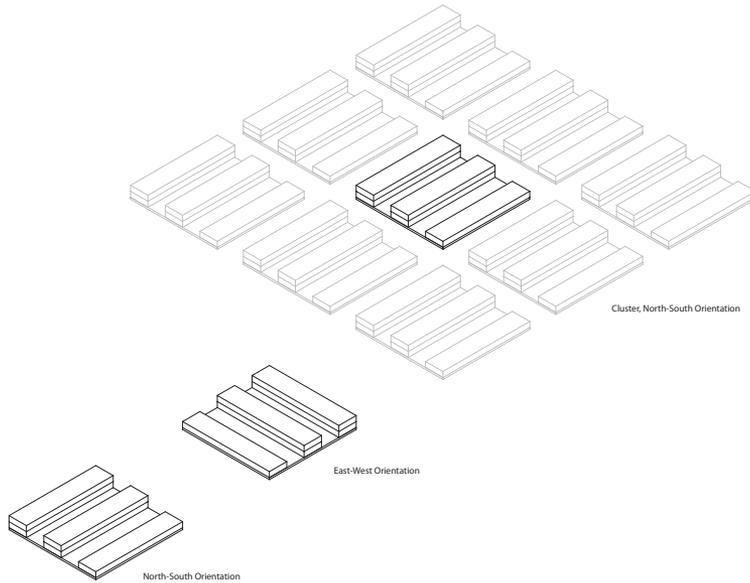


Figure 5.2 Overview of changes of direction and environment

All geometry was drawn in 3D in AutoCAD and imported into the BPS tool Ecotect (Autodesk, 2011) with all floors ten metres deep and three metres high. In Ecotect, a solar access analysis was run, looking at the incident solar radiation over a whole year in the city of Lund, Sweden (N55.705, E13.191) on the building envelope of the urban block. Within Ecotect, the surfaces selected were those with an annual solar radiation above 650 kWh/m<sup>2</sup>year. This value was chosen because with a 15% efficient PV cell, this would lead to a production of around 100 kWh/m<sup>2</sup>year; for solar thermal it would roughly mean a production of 250 kWh/m<sup>2</sup>year, which are realistic targets to meet the energy need of actual building constructions. Furthermore, the solar panel area was considered to be 75% of the facade area, leaving 25% for fenestration. This is a realistic value since too much fenestration will lead to visual problems and overheating (Dubois & Blomsterberg, 2011). The same ratio was chosen for the roof, since there is a need for space for maintenance of the roof and the installation.

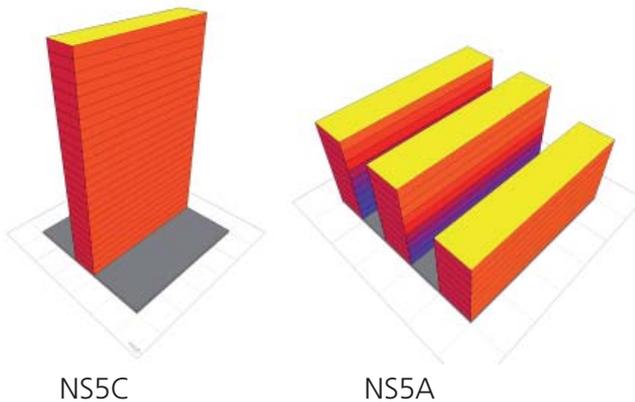
Solar panels were considered to be PV cells, but a similar method can be used for ST. The electricity use of the buildings was considered to be 50 kWh/m<sup>2</sup>year. On average, 30 kWh/m<sup>2</sup>year is taken as an indication for the amount of household electricity used annually in Sweden. An additional 20 kWh/m<sup>2</sup>year was taken to cover common energy use, such as the ventilation system etc. The electricity coverage was calculated by

dividing the annual solar produced electricity in a building by the annual electricity demand in the building. The incident solar radiation was simulated annually, so the problem of seasonal imbalance between energy production and need was not taken into account, but was assumed to be dealt with by for instance selling energy to the grid. The production and need for DHW was also not considered in this research.

### 5.1.2 Comparison of Ecotect and DIVA-for-Rhino

With the help of BPS tools, the solar radiation on building surfaces can be calculated. In this study, two BPS tools, Ecotect 2011 and DIVA-for-Rhino 2.0 (Jakubiec & Reinhart, 2011), are compared to each other to bring forward the advantages and disadvantages of each tool, similar to a study conducted earlier by Ibara and Reinhart (2011).

Two urban blocks were used for the comparison; one block North-South orientated, FSI=5, and design C, the other block was North-South orientated, FSI=5, and design A (Figure 5.3).



*Figure 5.3 the compared building blocks*

Within Ecotect, the geometry was modelled within the program itself; in case of DIVA, the geometry was modelled within the CAD program Rhinoceros (McNeel, 2011). Both programs performed an annual solar radiation calculation with the same weather data. For the urban block configuration NS5A (North – South orientation, FSI = 5, design option = A), the comparison of the annual solar radiation values on several surfaces are shown in Table 5.1.

Table 5.1 Annual solar radiation values on different places of the building envelope (values in kWh/m<sup>2</sup>year). E = value in Ecotect, D = value in DIVA, Diff.= Absolute value difference between Ecotect-DIVA, and also as relative difference (in %).

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.
669	741	-72 / <b>10,8%</b>	292	220	+72 / <b>24,7%</b>	487	482	+5 / <b>1,0%</b>	453	500	-47 / <b>10,4%</b>	967	970	-3 / <b>0,3%</b>

For the urban block configuration NS5C (North – South orientation, FSI = 5, design option = C), the comparison of the annual solar radiation values is shown in Table 5.2.

Table 5.2 Annual solar radiation values on different places of the building envelope (values in kWh/m<sup>2</sup>year). E = value in Ecotect, D = value in DIVA, Diff.= Absolute value difference between Ecotect-DIVA, and also as relative difference (in %).

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.
670	780	-110 / <b>16,4%</b>	293	221	+72 / <b>24,5%</b>	487	482	+5 / <b>1%</b>	453	500	-47 / <b>10,4%</b>	985	976	+9 / <b>0,9%</b>

The comparison shows that the simulations made in both Ecotect and DIVA differ significantly for mostly surfaces orientated to South and North, with relative differences of ~10-30% (see also Figure 5.4).

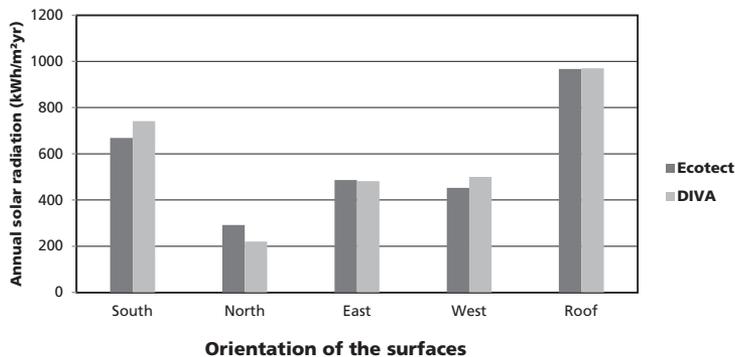


Figure 5.4 Comparison of Ecotect and DIVA-for-Rhino for block NS5C

The results show that surfaces directed towards East and horizontal surfaces had the lowest differences between the two programs. Differences in values are due to the difference in calculation methods in the two programs: DIVA-for-Rhino is a Radiance-based, backward-ray-tracing algorithm program which uses the Perez Sky Model, Ecotect uses hourly recorded direct and diffuse radiation data from the weather file (Strømmandersen & Sattrup, 2011). Even though Radiance is currently used more widely and is better validated than Ecotect, the latter has become the industry's common practice for solar insolation analysis because of its ability to produce visual output and to simulate several other performance aspects, such as thermal, energy, lighting, shading, acoustics and cost, without the need for remodelling (Crawley et al., 2008; Ibara & Reinhart, 2011). Analysis of the output of DIVA-for-Rhino is more time-consuming when many surfaces are considered.

### 5.1.3 Geometry input and simulation options

The geometry can be input into Ecotect in two ways: by importing external geometry or by drawing the geometry within the program itself (Autodesk, 2011). In this case, geometry was drawn in Autodesk AutoCAD, exported to the .ifc file format and then imported into Ecotect. When geometry is imported into Ecotect, it is important to first ensure that the surface normals are facing the right way. If surface normals are not directed outwards, Ecotect will perform calculations with the wrong input and will therefore return wrong results.

Two important points in running simulations in Ecotect are 1) resolution of geometry, and 2) simulation options. The building geometry is an important input factor for all further calculations in a BPS tool. Geometry needs to be built in such a way that no unwanted surfaces are present in the model (resulting in additional time removing them). Another important factor is the resolution of the geometry. Building mass can be built up in several ways. In order to find out how this resolution will affect calculations and calculation time, a building mass was constructed in three different ways: the facade area as one piece, the facade area divided per floor, and the facade area divided by half the floor height (Figure 5.5). A simulation of the annual solar insolation was performed with these three different ways of constructing geometry. Furthermore, it was important to look at how simulation options affected the results and calculation time. In order to do so, buildings were simulated both with a 'medium' and a 'high' setup (Table 5.3). The surface sampling as well as the sky subdivision was changed. The results of these simulations are shown in Figures 5.6, 5.7, and 5.8.

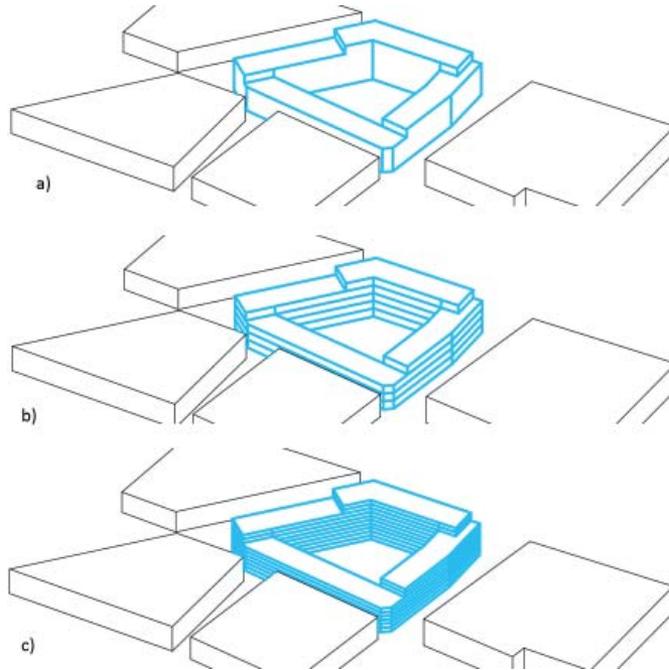


Figure 5.5 Different resolutions of the geometry (a) 1 piece, b) per floor, c) per  $\frac{1}{2}$  floor)

Table 5.3 Difference in setup in Ecotect

Medium setup:	
Surface sampling:	Grid divided by $5 \times 5$ elements
Sky subdivision:	$5^\circ \times 5^\circ$
High setup:	
Surface sampling:	Grid divided by $10 \times 10$ elements
Sky subdivision:	$4^\circ \times 3^\circ$

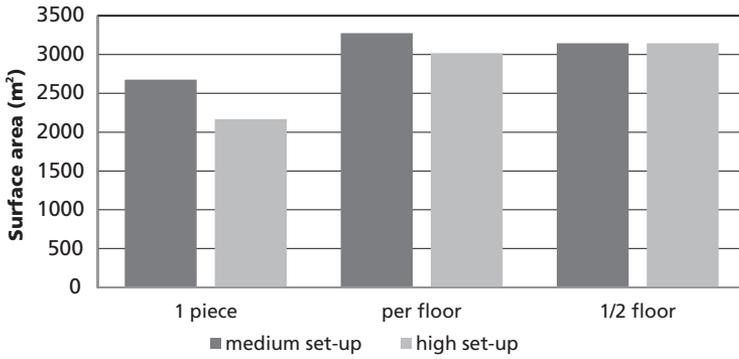


Figure 5.6 Surface area hit by solar radiation for different geometric resolutions

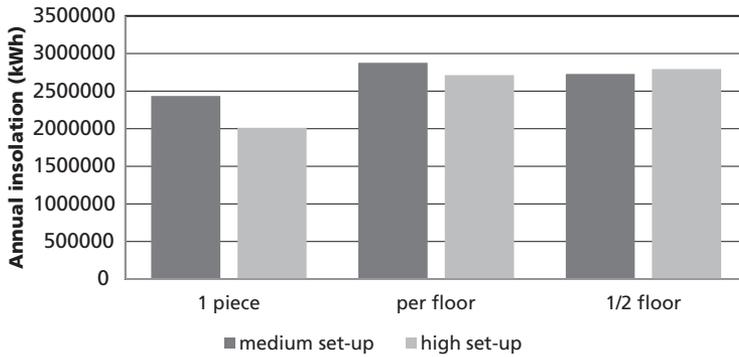


Figure 5.7 Annual insolation for different geometric resolutions

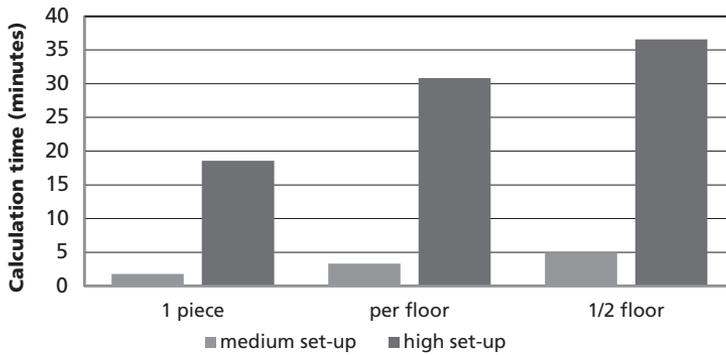


Figure 5.8 Difference in calculation time (minutes)

As regards the difference in resolution, it is apparent that the differences between the geometry options ‘per floor’ and ‘1/2 floor’ do not differ that much from each other for area and insolation, while the difference of the option ‘1 piece’ and the other two options is much larger. This was expected, since Ecotect provides the average value per surface. On the lower part of the facade, there is less insolation than in the higher parts, with the result that a low average value does not reach the defined threshold.

As regards calculation time, it is clearly seen that the option ‘1/2 floor’ requires the largest calculation time, since it has a higher number of surfaces to calculate. It is also clear that the calculation time increases significantly when the simulation options are set to ‘high’ (calculation times were 70-100% longer). However, a higher setting in simulation options hardly affected the results of ‘area’ and ‘insolation’, so its necessity can be questioned, especially in the EDP when fast results are necessary.

#### 5.1.4 Results of the parametric study

In this section, the simulation results of a parametric study are presented. Figure 5.9 presents the visual results of some of the simulations performed in Ecotect.

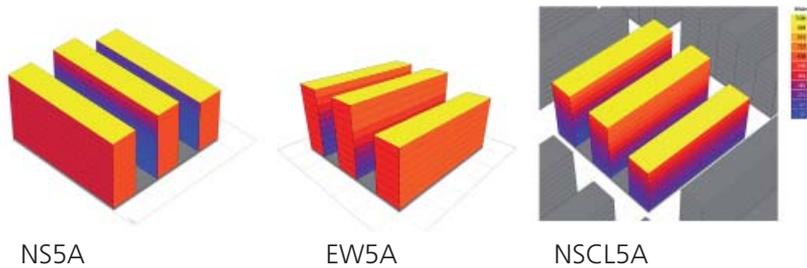


Figure 5.9 Graphical output of annual solar insolation in Ecotect

The solar performance of the blocks is divided into two: a) The PV potential—the percentage of the building envelope which receives an amount of solar radiation greater than or equal to a preset threshold (Cheng et al., 2006) and b) the electricity coverage—the annual electricity produced by the sun in a building divided by the annual electricity need, a unit which has been used in similar studies by Lundgren et al. (2010), Izquierdo et al. (2011), Wiginton et al. (2010), Jeppesen (2004), and Ordóñez et al. (2004). In the following parametric study, a threshold value of 650 kWh/m<sup>2</sup>year was used. Figure 5.10 shows the PV potential of the different

building blocks in different settings. The X-axis shows the plot ratio of all the blocks, the Y-axis the PV potential.

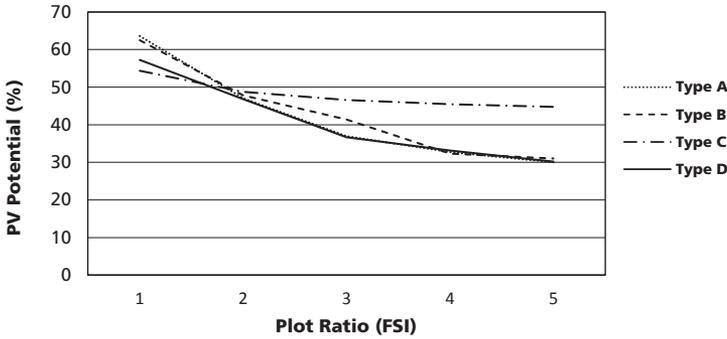


Figure 5.10.a PV potential of the blocks in North-South orientation

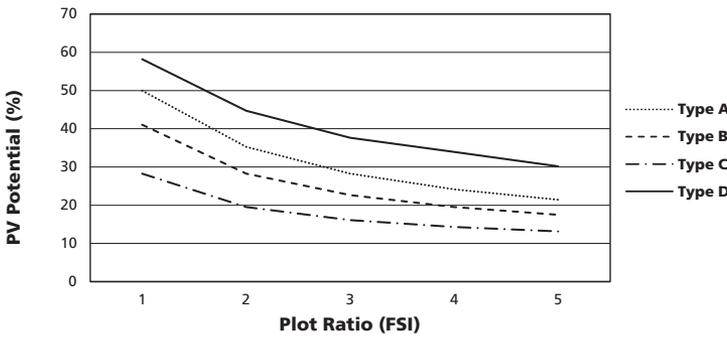


Figure 5.10.b PV potential of the blocks in East-West orientation

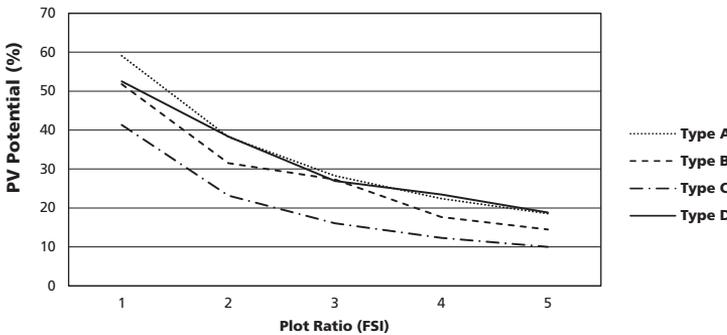


Figure 5.10.c PV potential of the blocks in cluster formation, North-South orientation

Although the initial values are not the same owing to the difference in design, it can be seen that, in general, the decline of the PV potential per case is the same: from FSI 1 to FSI 3, the decline is sharp, but it tends to stabilise when the density gets higher than FSI = 3 (except for Type C in the North-South orientation).

Type C in the North-South orientation also shows different behaviour (Figure 5.10.a). Even in cases of a high FSI (5), 45% of its building envelope still receives more than the threshold annually. In the case of the East-West orientation and FSI=5, the PV potential of all building blocks is still 15-30% (Figure 5.10.b). Furthermore, increasing the FSI from 1 to 5 in the North-South orientation will decrease the potential by around 50%, except for Type C (Figure 5.10.a). Increasing the FSI from 1 to 5 in the East-West orientation will also decrease the PV potential by around 50% (Figure 5.10.b). In the clustered, North-South orientation, the PV potential dropped by 70-75% when the FSI increased from 1 to 5 (Figure 5.10.c). This is a much higher decline compared with the two other cases without surrounding geometry and displays the effect of shading from surrounding buildings on the building blocks. In all cases, the results imply that a relatively big part of the building envelope can be used to generate energy in many orientations.

The electricity coverage of the building blocks in different orientation is shown in Figure 5.11.

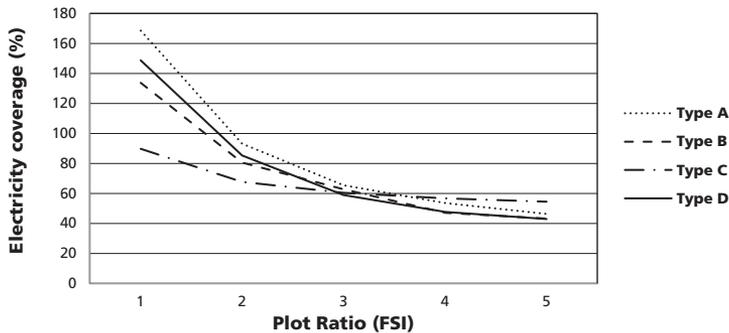


Figure 5.11.a Electricity coverage of the blocks in North-South orientation

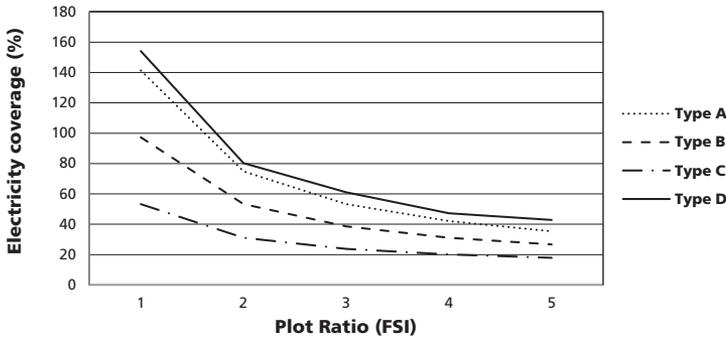


Figure 5.11.b Electricity coverage of the blocks in East-West orientation

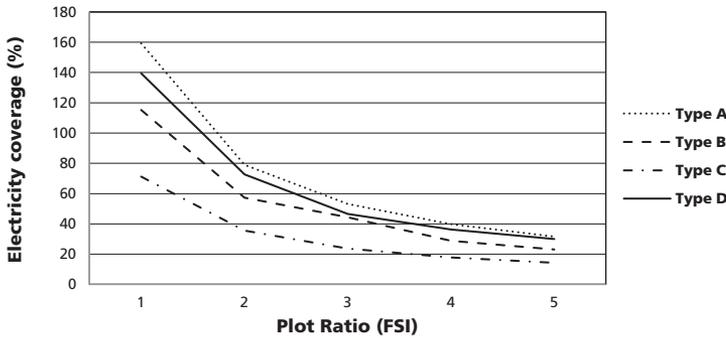


Figure 5.11.c Electricity coverage of the blocks in Cluster configuration, North-South orientation

When calculated annually, in 8 out of 60 cases, the electricity need can be met with locally produced electricity with the preset assumptions. In order to become Net Zero Energy Buildings, heat and DHW will also need to be provided by local sources. In all other cases, the electricity demand cannot be met with PVs. The variation in the range of coverage is rather wide: the highest coverage is 169%, while the lowest coverage is 14%.

Results show that the impact of geometry on the solar potential was significant: In most cases, Type C gave the worst coverage while Type A gave the best performance. Type D was relatively less sensitive to rotation from North-South to East-West direction. This was obviously due to the design of Type D, which has almost the same surface area to East, West,

North, and South. Interestingly, Type D outperformed Type B when it comes to electricity coverage.

When the urban blocks were surrounded by other geometry, the coverage decreased by 6% to 74% due to shading by the adjacent geometry. Figure 5.12 shows the reduction in the electricity coverage due to surrounding buildings. In this graph, the difference between the North-South orientation and the cluster orientation represents this influence. The graph shows that Type C is very sensitive when it is placed in a densely built environment. Type B is the second most sensitive design, while Type A and D show almost the same increase when placed in a densely built environment.

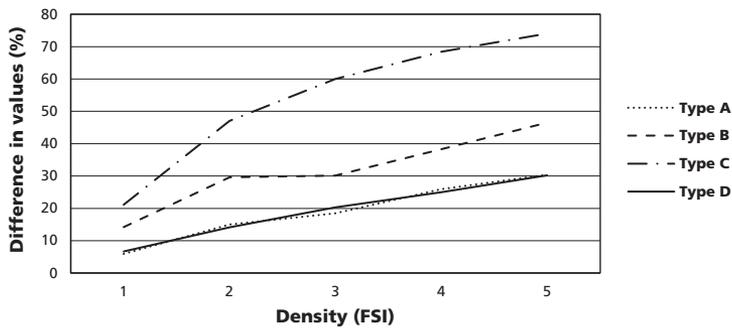


Figure 5.12 Reduction of electricity coverage (%) due to surrounding buildings

The production of electricity did not always meet the electricity need. In the parametric study, only the electricity need was taken into account, not the heat and DHW need. If these two components had been taken into account, the question whether to produce heat or electricity on which places in the building would have become very important. The fact that the annual solar energy production is not able to totally meet the energy need of buildings in cities shows that other renewable energy sources also have to be used. Furthermore, a returning conflict for solar energy is the competition with the green roofs and urban gardening, a topic which is becoming more relevant as cities become bigger.

Certain designs of building blocks performed better than others in the simulations, especially when the blocks were surrounded by a densely built environment. Interestingly, it could be noted that types A and D are similar to European building layouts, while type C is more similar to North American urban standards. When the density was 1, almost all design options were able to meet the energy need with solar systems. When the FSI was increased, building blocks were not able to meet all the energy needs

with locally produced energy. In one case, the solar potential decreased by 75% when it was placed in a densely built environment, which means that the electricity coverage of this design was very low.

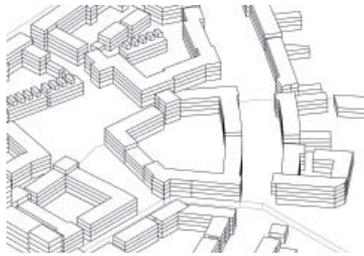
## 5.2 Process guidelines

Urban planning is a process in which many factors play a role; Solar energy is just one of these and it has been hard for urban planners to quantify the role of solar energy. When done properly, taking solar energy into account when a new urban district is designed can provide a significant contribution to the local production of renewable energy, as was demonstrated with the parametric study. Urban planners should be informed about the consequences of building blocks' layout on the solar potential. In an ideal situation, one actor in the design process should perform the simulations and calculations regarding the solar potential as described in this chapter. This actor could be an external consultant, an urban planner or an architect. The further in the design process this is done, the more in-depth the solar potential can be analysed. Important issues in these analyses are: the production of the active solar systems (kWh), the production over the year, the energy need of the building(s), the ratio between PV and ST, architectural integration issues (colour, texture, dimensions) etc.

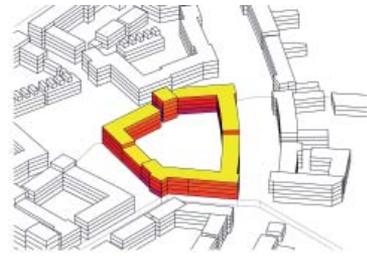
Another important issue is the role of tools regarding solar energy. BPS tools can be of great help to urban planners and other actors for determining which option is most suitable, but they should be used with care. The preconditions of a particular BPS tool should be clear to the user; the needed input of the tool, its validation, the output, and the required technical knowledge. When different design alternatives are compared with each other, it might be more interesting to look at relative values rather than absolute values of energy output and energy need. Also, relative values and trends as results from simulation programs are often more accurate than the use of absolute values from specific programs, to make early design decisions.

The parametric study formed the start for the development of a working method. The ultimate goal is to implement solar energy into the daily practice of urban planners and architects. In order to understand how this could be fitted into the current design practice of urban planners, meetings were organised in the planning departments of the Swedish cities of Malmö and Lund within the framework of a research project on the implementation of solar energy into urban planning. Both cities expressed a will to implement more solar energy into future urban districts. The cities provided all 3D material for the newly planned urban districts. A

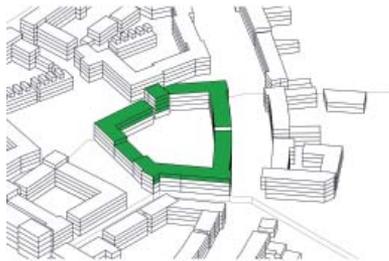
theoretical working method was developed and tested with the cases of both cities Malmö and Lund, which can be seen in Figure 5.13.



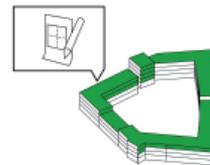
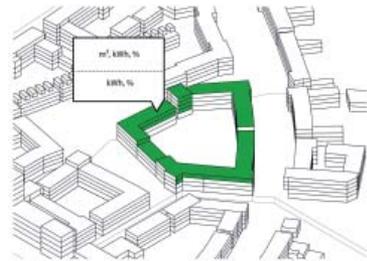
Step 1. Design alternative is developed, building is available in 3D.



Step 2. A simulation is run for the annual solar insolation



Step 3. All surfaces above a certain threshold are shown visually and numerically



Steps 4 and 5. If the design alternative is performed as planned, information is given to the architects. Otherwise, a new design alternative will be developed and will go through steps 1-4.

Figure 5.13 Visualisation of a possible working method for site planning in an urban environment

The method consists of five steps: 1) a design alternative is developed and drawn in 3D, 2) the annual solar insolation is simulated, 3) by setting a certain threshold (in this case 650 kWh/m<sup>2</sup>/year), a certain part of the building envelope is selected as the most appropriate for harvesting solar energy. This is visualised both graphically and numerically. Step 4 is the evaluation phase: does the design alternative live up to the expectations? If not, then other design alternatives are proposed and will go through steps

1-3, otherwise the process goes on to step 5. In step 5, both the graphical and numerical output of the solar potential is given to the architects who will design the building in detail. It is important that this knowledge transfer is done properly so that the information is not lost in later design phases. In such a way, design alternatives can be compared with each other for their solar potential and performance.

## 6 Discussion and conclusions

Solar energy can be exploited in our built environment much more than at present. The aim of this research was to gain insight in how solar energy is currently implemented into the design process of Scandinavian architects and urban planners, and to start development of a working method for implementing more solar energy in the design process from large to small scale. The literature, the interviews and the development of the working method have shown that taking solar energy into account in the design process needs careful consideration, and thus puts pressure on the competences of architects, clients, municipalities, and engineers.

### 6.1 Literature

Design processes have been the subject of many studies. It has proven to be very hard to map such complex processes, since the number of actors, the type and size of building, the type of client, the knowledge needed, and the tools used, are all complicating factors in this process. The literature does not provide a process map for designing solar buildings, something which would be useful in order to explore what decisions are to be taken by whom with what competence.

Another clear line in literature is the development of new active solar technologies. In this development, the driving force is often efficiency improvement, cost reduction or the reduction of harmful materials, but it is seldom driven by architectural reasons.

The perfect BPS tool does not exist (yet): many studies described the dissatisfaction with current BPS tools, leading to the development of new ones. New tools described in literature are often developed by researchers and will, unfortunately, often be used by researchers alone because of their complexity. However, commercial software developers seem to have discovered that there is a growing market for BPS tools, which is confirmed by the recent launch of new (commercial) BPS tools.

## 6.2 Interviews

The interviews with architects in Denmark, Norway and Sweden have shown that collaboration between all actors has become even more crucial and important when solar and low energy architecture is designed. New forms of design processes can help all actors to collaborate in an effective and fruitful way, with the IDP as the most well-known design process for designing low energy buildings. Its main features are the early involvement of engineers, the setting of common goals and the interdisciplinary attitude and collaboration. This collaboration, together with the necessary acquisition of more technical knowledge, was considered as the key factor for a successful project. A difference of management structure in architectural offices became clear. In Sweden, architectural offices mainly initiate collaborations with external engineers, while many Danish architectural offices had their own engineering departments. This might be due to the difference in the sizes of architectural offices. Many Danish architects were also able to work with advanced BPS tools themselves, while Swedish and Norwegian architects hardly used advanced BPS tools.

The design processes of this study have shown that tougher building regulations and the rise of building assessment methods have caused real estate developers and / or clients to be more willing to invest in solar energy. It is therefore very important to inform clients about solar energy and all its aspects: the foreseen energy production, the impact on the architecture, and costs. It is however unclear who it is that should take this role, since the application of solar energy needs to be considered from the urban scale to the detailed building scale.

More use of solar energy in our built environment will only be possible when the whole chain of actors is engaged in this endeavour; from urban planners to the design team, the real estate developers to the occupant. Unfortunately, almost all interviewees considered costs and payback time as the biggest barrier to the use of solar energy, which is a factor mostly related to the real estate developer. Currently, if no subsidies are provided and there is no chance of selling energy to the grid, most real estate developers consider the payback time to be too long. The first aspect is a political issue; if governments do not put effort and money into solving this problem, the situation will not change. As regards the second aspect, real estate developers need to go off beaten tracks. Long term commitments for owning and maintaining buildings will make solar energy more profitable since payback times are longer than the standard considered 5 years. A positive development is the constant drop in the prices of PV systems: in Germany prices went from 5000 €/kW<sub>peak</sub> in 2006 to 1776 €/kW<sub>peak</sub> in 2012 (German Solar Industry Association, 2012).

Municipalities and national building regulations put requirements on the energy use per square metre of building per year. When these building regulations become stricter regarding energy use, the building industry, construction companies and real estate developers will be forced to make sure their buildings do reach these levels. In the current situation, energy production targets for buildings are not defined. One approach for changing this situation is by including minimum requirements for energy production. From 2006, Spanish national building regulations are requiring solar energy (PV/ST) in newly built homes and renovations, resulting in higher implementation and lower prices (Pérez, 2009). However, since no demands were put on the quality of the active solar systems, this also led to lower quality of installation practices and thus a worse integration of the systems. If the quality of building integrated systems can be ensured, then a gradual increase in such demands will become a factor which needs to be looked at when new buildings are designed and planned.

Unfortunately, the role of the architect is relatively limited when it comes to persuading the client in favour of the implementation of active solar technologies. If the client is willing to invest in solar energy, the design team needs to identify the best way of physically integrating such systems into the architecture of the building. If the client is not willing to invest in solar energy, then the instruments that architects can use are limited. Since many architects lack knowledge about costs and payback times as well as technical details, such as the energy output of systems, it is hard for them to persuade their clients. Therefore, it might be necessary to consult an external solar energy expert.

### 6.3 Working method

BPS tools can provide architects and engineers with feedback on the design alternatives developed during the design process. By comparing different design alternatives and their effect on the energy performance, valuable information is provided to the design team, which may influence the development of the design. The latest BPS tools offer the possibility to quantify the solar potential of buildings in complex urban environments, but they are not fully developed yet.

Even though several BPS tools exist that are capable of calculating the contribution of solar energy, there is no clear working method. Important issues that need to be solved are 1) what information is needed when, 2) how can this information be obtained, 3) how can this information be communicated to several actors in the design process?

## 6.4 Future work

In order for solar energy to become a parameter which urban planners and architects can easily take into account, the preliminary method as developed in Chapter 5 will need to be refined and extended. Furthermore, it should be possible to look at both existing buildings and new buildings.

Important questions in the development of this method are:

- tool issues
  - o overview of simulation and design tools used for solar energy (solar potential, assessment/evaluation/validation of tools)
  - o use and import of geometry (interaction between different programs)
- financial issues
  - o threshold value (which threshold value can still be considered as financially feasible)
  - o balance between Solar Thermal and PV (which form of energy will reduce costs and / or will generate money)
- questions of aesthetic integration of active solar systems

By addressing these issues, the role of solar energy becomes quantifiable; making it easier to integrate it into the design workflow and design process. Not only should the content of these issues be discussed, it should also become clear which issue requires which competence. In that way, a decision can be made which actor is responsible for which part.

The method needs to be disseminated in order to reach urban planners and architects.

# Summary

Newer, stricter building regulations in Europe require nearly zero energy use in future buildings. These requirements have a direct impact on 1) the architecture of buildings, 2) their design process, and 3) the tools that architects are using. It will require more technical knowledge by architects as well as better collaboration between the actors involved in the design process. Solar energy has an important role to play in future low energy architecture; consideration of both the active and passive use of solar energy will lead to solar integrated architecture. The impact of passive solar design is mainly on dimensions of outer walls, placement of windows, solar shading, and the location of functions in a building. Active solar design has consequences on the building shell and installations (it requires spaces to store energy). A building integration of solar components in a building is often successful when it is taken into account early in the design process and when those components are considered holistically as a part of the building design.

The design process of low energy buildings has started to shift from the traditional design process to the Integrated Design Process (IDP). This design process is characterised by the early involvement of other actors –mainly engineers- in order to support the design team in making informed decisions. The architect does play a new role in the process since he / she often becomes team leader, while other actors have more influence. The IDP is a theoretical model for a design process which might not always be applicable in all building projects.

In order to validate several design alternatives in the design process (a process called evidence-based design), a new sort of simulation tool is necessary which can inform architects and other actors about the energy impact of the building. Currently, the launch of several Building Performance Simulation (BPS) tools into the Computer Aided Architectural Design environment is a first step in this direction. Parametric design - the use of parameters to define a form – might be another way to implement energy factors, as well as solar energy, into the design process in the future.

## Literature review

A literature review was conducted on the topics: design process, solar architecture, design tools, and education on solar architecture.

When it comes to the design process, several attempts have been made to map the involved actors and their actions for different reasons. It has led to imaginary design process maps, which do not really represent the factual process, since this is different for every project. Mapping the design process is a useful exercise in order to get an overview of possible problems within the design process and to find ways to improve the effectiveness of design processes.

Several articles have outlined the evolution from the traditional design processes towards newer design processes for low energy buildings. The IDP has proven to be effective as the design process for low energy buildings. It is mainly characterised by the collaboration of all actors from the very early design phase, with an emphasis on the early involvement of engineers.

The evolution regarding the actors involved also results in new maps of the design process. Even though more architects seem to be aware of the IDP, some issues need attention: the client should be willing to pay for the earlier involvement of all actors, and there should be a team leader who is preferably educated for this job. In many IDPs, there is also a facilitator.

The integration of solar energy strategies –passive and active- within our built environment has been mostly described with the help of case study buildings. The integration of active solar technologies is clearly over-represented in scientific articles of the last decade; active technologies are presumably easier to describe than passive solar strategies, both in their efficiency and in their features (colour, texture, etc). An explanation might be that passive solar strategies are considered to be well-known strategies. It is important to introduce active and passive solar strategies early in the design process, both for new buildings and for renovations. This early introduction is necessary in order to gain more information about the technology, but also since it needs more careful consideration of, for example, the placement, orientation, and texture of the solar panels. The development of new active solar components is often focused on higher efficiencies, as well as on combining different technologies. However, the latter needs to be considered systematically; in one example, the combination of several technologies into one element only reduced the auxiliary energy by half compared with the situation if all elements were installed separately on the building.

The literature review concerning design tools reveals the limitations of current design tools. Until now, most BPS tools have not been suited for use by architects, and most of them are still used only by engineers and

researchers. BPS programs could make it easier for architects to compare different design alternatives with each other so the best option can be chosen. It can be concluded that the perfect BPS tool does not exist yet. Users of BPS programs have their own preferences: it should be possible to choose from several high quality BPS tools. However, the literature does not agree on what such high quality BPS tools should look like and what components such a tool should have. Important components mentioned in the literature are:

- User-friendly interface
- Calculation speed
- Reliability of results
- Interoperability
- Ability to suit the early design phase when not much is known about the project

Interestingly, the components mentioned might conflict with each other; reliable results are often obtained when the input of data is precise, which results in longer calculation times and also requires more technical knowledge.

Architectural education can help to prepare future architects for designing low energy architecture. Several schools of architecture have started courses on low energy architecture. The key word in these courses is the multidisciplinary character; students of several disciplines are working together, possibly even combined with the industry. Such interdisciplinary collaborations are relatively new within the architectural curriculum, but are found to be necessary. It will also help students to prepare for their future work environment, where collaboration is so important.

### Interviews

During 2011, 23 architects in Denmark, Norway, and Sweden were interviewed who had implemented solar energy into a building or urban planning.

Concerning solar integrated architecture and its design process, the following main issues were identified as important by the interviewed architects:

For a sustainable project, all the involved actors should endeavour to achieve the following:

- the client: to make it financially possible;
- the engineers: to make it technically possible;
- the municipality: to make it legally possible;

- the architect: to make it into an attractive, functional and healthy building pleasant for its inhabitants

However, it was not found to be as simple as that. As teamwork and collaboration becomes crucial, more intense and necessary, it becomes more important for all actors to speak 'the same language'. Architects experienced a gap between engineers and architects because of different backgrounds, resulting in difficulties of communication. With the need for more clever, energy efficient buildings, it could be said that architects need more engineering skills while engineers need to gain more architectural skills. As we see that IDP is becoming a more common and necessary design method, it should preferably be introduced in education. Learning how to successfully collaborate within the design team should become part of both the architectural curriculum and the engineering curriculum in order to reduce problems in future IDPs.

Clients did not prioritise solar integrated architecture. This was mainly due to a resistance to investing in active solar technologies, which did not provide short-term profit. Architects mentioned that a change in the type of ownership –one which prioritises a long-term commitment- would stimulate the integration of active solar technologies. This change was seen possible if it were stimulated by subsidies or other financial incentives. Green building certification systems were often seen by architects as a positive influence for the implementation of solar energy in the building process, because clients will more easily invest in sustainable (solar) aspects for the sake of marketing. However, a certain caution is needed when it comes to certification systems. For instance, Building Assessment Methods certifications offer no guarantee of a better energy performance (Shaviv, 2011).

All interviewed architects mentioned to have used rules of thumb as a design tool. These rules provided them with basic information and would orientate architects in the right direction in the early design phase. Architects do use rules of thumb for other aspects during the very early design phase, for instance for estimating the approximate size of structural elements, as these sizes can greatly affect spaces within the building. Structural engineers make more detailed calculations in the later design phase and will adjust the sizing according to these. Rules of thumb regarding energy aspects can also help architects in the very early design phase but they are not a substitute for energy simulations, which are needed at later stages (Granadeiro, Duarte, & Palensky, 2011). In Sweden, advanced BPS were carried out by (building services) engineers in order to provide more information for the architects and engineers to work with, but these advanced simulations were never performed by architects. In Denmark,

architects more often used BPS tools themselves, probably because they are obliged to do so to obtain a building permit.

In the interviews, the architects who used BPS tools often used more than one program at the same time during the design process to simulate several aspects of the energy performance of a building, e.g. daylight conditions, energy production of solar technologies, and thermal balance. Combining all such separate programs into one environment, using the same geometrical model, would be preferable and speed up the simulation process. The recent launches of several BPS tools with such features have made clear that the industry is working towards such programs.

There is a lack of aesthetically attractive active solar products. Most of the architects would like to consider active solar systems more as a building material, with the opportunities to change colour and dimensions.

### Working method

A preliminary working method for implementing photovoltaics into buildings in urban environments is set up. It focuses on new buildings and on the first phases of the design process, where urban planners have defined building blocks and property developers have started to develop their plans together with architects. The preliminary method consists of several steps which have to be achieved.

1. The first step is the modelling of the building block, either in a CAAD program or in the simulation software itself. The model needs to be carefully built up and imported in the BPS program in order to get the right results, with a special care on the normals of the surfaces, which need to be directed outwards. Interchanging geometry between CAAD programs and BPS tools can be time consuming; one way to exchange geometry is to use the IFC file format.
2. The second step is an annual solar radiation simulation on all the building surfaces. In this method, the BPS tool Ecotect is used to perform this calculation. A surface sampling of a 5x5 grid and a sky subdivision of 5°x5° was used. Data on solar radiation levels on all building surfaces is exported from Ecotect and imported into Excel. A selection is made at a threshold value. In this case, 650 kWh/m<sup>2</sup>year was chosen, meaning that all surfaces were selected as suitable (regarding energy production criteria) for solar cells when the total sum of solar radiation on a surface was more than 650 kWh/m<sup>2</sup>year.
3. The suitable areas are shown graphically as well as numerically. Graphically, the surfaces are shown where the highest energy production can be achieved. Numerically, the energy production of all the suitable areas is shown in kWh as well as the area.

4. In this step, it is decided whether the building block fulfils all the pre-set requirements. If not, an alternative design is proposed and tested through step 1-3 again. Otherwise, step 5 is taken.
5. All information regarding solar energy on the building block is given to the design team and architects who are working on the project. In such a way, general information is available for all actors.

The presented preliminary method needs improvement in order to become fully functional. Important issues to solve are: how to balance between solar thermal and photovoltaics, financial issues, finding an appropriate threshold value, monthly analyses between energy need and production, and questions of aesthetic integration.

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## Solar energy as a design parameter in urban planning

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### Abstract

By the end of 2020, all EU member states need to ensure that all newly constructed buildings consume ‘nearly zero’ energy and that their energy needs are produced locally as much as possible and with renewable sources; a concept called nearly Zero Energy Buildings (ZEB). At the same time, more and more people live in cities, where the access to local renewable energy sources –wind and solar- is limited. Planning for such ZEBs in cities is therefore a difficult task since urban planners often do not have the technical knowledge to quantify the contribution of solar energy in their urban plans. This study shows an exploration of geometrical forms of urban blocks and the potential of solar energy to the local production of energy. Simulations were performed with the program Ecotect for the city of Lund in southern Sweden. It was found that the impact of the geometry form on the potential of solar energy was significant (up to twice as much) and some forms were found to be less sensitive for different orientations. When the urban blocks were surrounded by other geometry, which resembles the situation of a dense city, the contribution of solar energy decreased by 10-75%.

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*Keywords: solar energy; solar zoning, urban plannin, urban morphology, architecture, insolation, parametric study*

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### 1. Introduction

More and more people are living in cities and this development seems to continue in the future [1]. In Europe, cities are home to nearly 80% of the population, resulting in the production of 75% of all CO<sub>2</sub> emissions [2]. The urban scale has often been neglected in the debate of energy consumption and climate change [3-4], although data showed that savings in energy cost of 20-50% are possible through integrated

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planning by carefully considering site orientation and passive strategies [3]. An extensive utilisation of solar radiation in urban areas appears to be essential and a practicable strategy but has a big impact on the formation of cities in order to be fully effective [5-6]. Another challenge is that, in Europe by the end of 2020, all newly constructed buildings need to consume 'nearly zero energy' and that their needed energy needs to be produced locally as much as possible and with renewable sources [7]. This requirement might be hard to meet in dense cities, where access to local renewable energy sources is limited. In addition, often urban planners do not have the technical knowledge to quantify the potential of solar energy the design process.

Being able to understand the solar potential is also important for architects when designing buildings in urban environments. Integrating solar energy on the building level, with roofs and facades as the most logical places to harvest solar energy, needs to be carefully considered as it significantly affects the architecture. When the integration of active solar technologies is taken into account early in the design process, it is more likely to lead to more attractive solutions [8-10]. The early integration might be made easier when architects are aware of locations where most energy can be produced. The solar potential can also function as an important tool for real estate developers, who can directly see the amount of energy which can be produced on the building envelope.

In order to aid urban planners and architects in their design process, a broad set of guidelines needs to be developed. This parametric study may be the first step in that direction, as it analyses different types of urban blocks and their potential contribution to locally produced energy. By this, the study will attempt to quantify the role of solar energy as a renewable energy source in various urban morphologies.

## 2. Method

This parametric study consisted of a range of four urban blocks, each with a different design (A, B,C, D). In order to see the impact of density in urban plans, the Floor Space Index (FSI) / Plot Ratio of the urban blocks ranged from 1-5. Both the design options A,B,C,D and the FSI range can be seen in Figure 1.

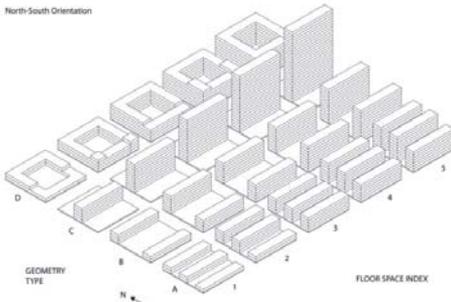


Figure 1. Overview of geometry types in North-South orientation

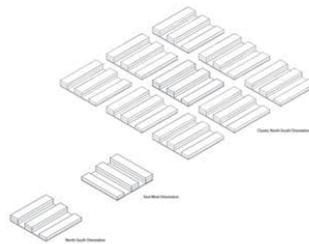


Figure 2. Overview of changes of direction and environment

Besides changing the form and the density of the blocks, orientation and environment was also changed: first, blocks were simulated in North-South (NS) direction, then in East-West (EW) direction. In the third case, blocks were placed North-South direction within surrounding buildings with the same density (Cluster / CL) (Figure 2).

All geometry was drawn in 3D in AutoCAD and imported into the Building Performance Simulation tool Ecotect [11] with all floors 10 metres wide and 3 metres high. Ecotect 2011 was chosen as the main simulation tool, since it enables the user to export a large amount of data to Excel, and the visual user interface was experienced to be easy to use. Another reason to use Ecotect was the fact that it is used extensively by the industry [12-13]. However, the authors were aware of the lack of transparency of Ecotect's calculation methods and reported possibility of errors as mentioned by Ibara and Reinhart [13], where the Building Performance Simulation tools Ecotect and DIVA with measured data were compared. DIVA is a Radiance-based simulation program which works within the CAAD program Rhinoceros. In this parametric study, a comparison between DIVA and Ecotect was performed to see how much the values differed by using the two different calculation methods.

In Ecotect, a solar access analysis was run using 'medium' settings, looking at the incident solar radiation over a whole year on the building envelope of the urban block, for the location of Lund, Sweden (N55.705, E13.191). Then, within Ecotect, surfaces with an annual solar radiation above 650 kWh/m<sup>2</sup>/year were identified and selected. This value was chosen because they can produce around 100 kWh/m<sup>2</sup>/year with a 15% efficient PV cell; for Solar Thermal it would roughly mean a production of 250 kWh/m<sup>2</sup>/year. Furthermore, the solar panel area was considered to be 75% of the facade area, leaving 25% for fenestration. The value of 25% for fenestration is realistic since too much fenestration can lead to visual problems and overheating [14]. The same ratio was chosen for the roof, since a certain portion of the roof surface is needed for maintenance of the building and building service installations. In this study, the solar panels were considered to be PV cells, but a similar method can be used for Solar Thermal. The electricity use of the buildings was considered to be 50 kWh/m<sup>2</sup>/year. Out of that, 30 kWh/m<sup>2</sup>/year is taken as an indication for the average household electricity used annually in Sweden. The remaining 20 kWh/m<sup>2</sup>/year was assumed to cover the shared energy use, like for the whole-building ventilation system, etc. The electricity coverage was calculated by dividing the annual solar produced electricity in a building by the annual electricity demand in the building. The incident solar radiation was simulated annually, meaning that the problem of seasonal imbalance between energy production and need was not taken into account here. The production and need for domestic hot water (DHW) was also not considered in this research.

### 3. Results

#### 3.1. Comparison Ecotect and DIVA.

First, a comparison was made between the simulation programs Ecotect 2011 and DIVA-for-Rhino 2.0 [15], similar to a study performed by Ibara and Reinhart [13]. This comparison was done to test how both simulation programs perform and how the output of the program is facilitated. Two models were tested for the annual solar insolation; one block North-South orientated, FSI=5, and design C (Figure 1), the other block was North-South orientated, FSI=5, and design A. The results are shown in Table 1.

Table 1. Difference in reference point on surfaces (values in kWh/m<sup>2</sup>/year)

North – South orientation, FSI = 5, design option = C (E=Ecotect, D=DIVA, Diff.= Absolute value difference Ecotect-DIVA / relative difference)

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.
670	780	-110 / 16,4%	293	221	+72 / 24,5%	487	482	+5 / 1%	453	500	-47 / 10,4%	985	976	+9 / 0,9%

North-South orientation, FSI = 5, design option = A

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff.
669	741	-72 / 10,8%	292	220	+72 / 24,7%	487	482	+5 / 1,0%	453	500	-47 / 10,4%	967	970	-3 / 0,3%
604	571	+33 / 5,5%	220	244	-24 / 10,9%									
512	354	+158 / 30,9%	192	189	+3 / 1,6%									
247	183	+64 / 25,9%	138	105	+33 / 23,9%									

Results show that the simulations done in both Ecotect and DIVA differ significantly for mostly the South and North, with relative differences of ~10-30%. Surfaces directed towards East and horizontal surfaces had the lowest differences. These differences are due to the difference in calculation methods in the two programs.

### 3.2. Results of the simulations

In this section the simulation results of the building blocks are presented. Figure 3 presents the visual results of some of the simulations in Ecotect for some of the building blocks.

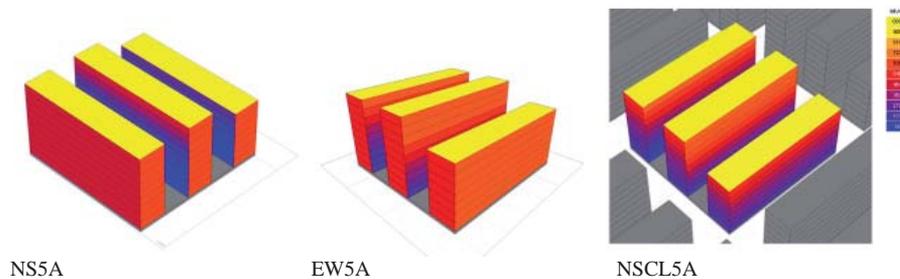


Figure 3. Graphical output of annual solar insolation in Ecotect

The solar performance of the blocks are divided into two parts: a) The PV potential –the percentage of building envelope which receives an amount of solar radiation greater than or equal to a preset threshold [16]- and b) the electricity coverage –the annual solar produced electricity in a building divided by the annual electricity need, a unit which has been used in similar studies by Izquierdo et al., Wiginton et al., Jeppesen and Ordóñez et al. [17-20]. Figure 4 shows the PV potential of the different building blocks in different settings.

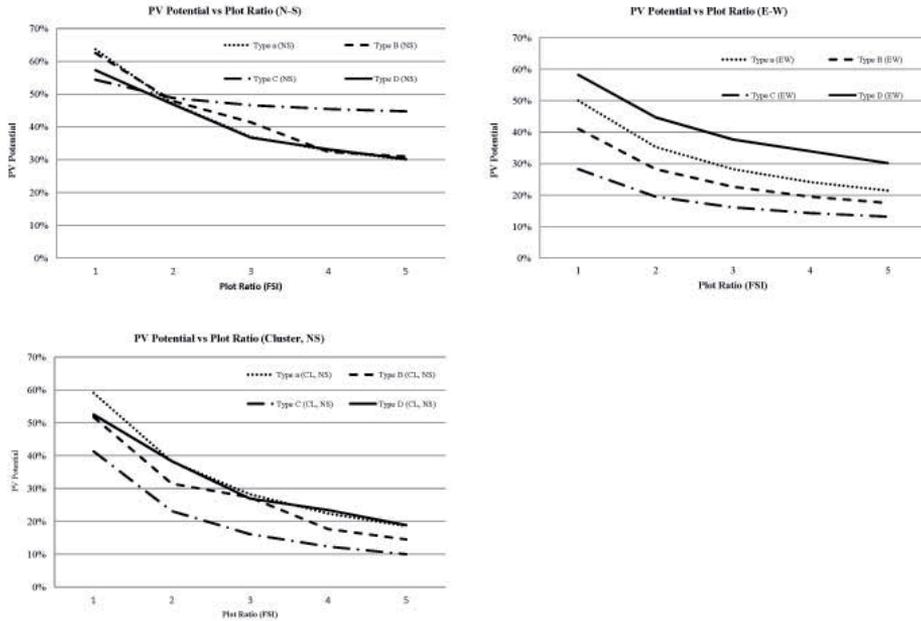


Figure 4. PV potential of the blocks

Although the start values are not the same due to the design, it can be seen that, in general, the decline of the PV potential per case is the same, except for the Type C, in the NS orientation.

Type B in the cluster setup also shows different behaviour. Even in cases of a high FSI (5), still 30-45% of the facade receives more than the threshold annually in case of the NS orientation. In the case of the EW orientation and FSI=5, the PV potential is still 15-30%. This implies that a relative big part of the facade can be used to generate energy on the building, which will have its impact on the architecture. Furthermore, increasing the FSI from 1 to 5 in the EW orientation will decrease the PV potential by 50%. Increasing the FSI from 1 to 5 in the NS orientation will also decrease the potential by 50%, except for Type C. In the situation with surrounding geometry, the PV potential dropped by 70-75% when FSI increased from 1 to 5, a much higher decline compared to the two other cases without surrounding geometry.

The electricity coverage of the buildings blocks are displayed in Table 2.

Table 2. Annual Electricity Coverage of photovoltaic cells in the buildings (in %)

FSI	Type A					Type B					Type C					Type D				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
NS	169	93	65	54	46	134	81	63	47	43	90	68	60	57	54	149	85	59	48	43
EW	141	75	53	42	35	97	53	39	31	27	53	31	24	20	18	154	80	61	47	43
Cluster	159	79	53	40	32	115	57	44	29	23	71	36	24	18	14	139	73	47	36	30

When calculated annually, in 8 out of 60 cases (13%), the electricity need can be met with locally produced electricity with the preset assumptions. In order to become Net Zero Energy Buildings, heat and DHW will also need to be provided by local sources. In all other cases, the electricity demand cannot be met with the solar cells. The range of coverage is rather wide: the highest coverage is 169%, while the lowest coverage is 14%.

Results show that the impact of geometry on the solar potential was significant: Type C gave in most cases the worst coverage while Type A gave the best performance. Type D was relatively less sensitive for rotating from North-South to East-West direction. This was obviously due to the design of Type D, which has almost equally much surface area to East, West, North, and South. Interestingly, Type D outperformed Type B when it comes to electricity coverage.

When the urban blocks were surrounded by other geometry, the coverage decreased by 6% to 74% due to shading of the adjacent geometry. Figure 5 shows the influence of surroundings on the electricity coverage; in the graph, the difference between the NS model and the cluster model represents this influence. The graph shows that Type C is very sensitive when it is placed in a dense built environment, especially with a high density. Type B is the second most sensitive design, while Type A and D show almost the same increase when placed in a dense built environment.

Effect of surroundings on electricity coverage

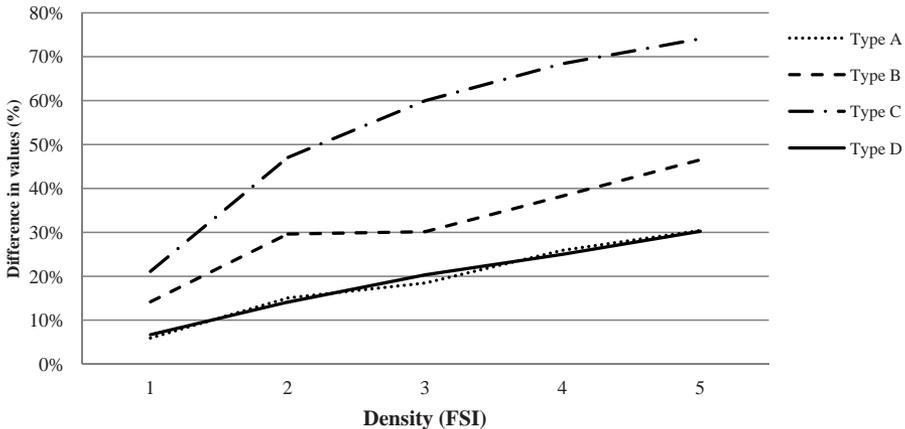


Figure 5. Effects of surroundings on electricity coverage of the simulated models

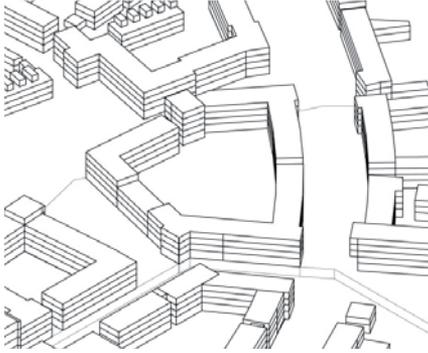
### 3.3. Implementation and future work

This parametric study represents a start of the development of a working method which ultimate goal is to implement solar energy into the daily practice of urban planners and architects. The next step was to understand how this could fit into the current design practice of urban planners. In order to do so meetings were set up between the authors and the planning departments of the cities Malmö and Lund, located in the south of Sweden. Both cities expressed a will to implement more solar energy into future buildings planned to be built in the near future. The cities provided all proposals' documentation and 3D digital models for the newly planned urban districts.

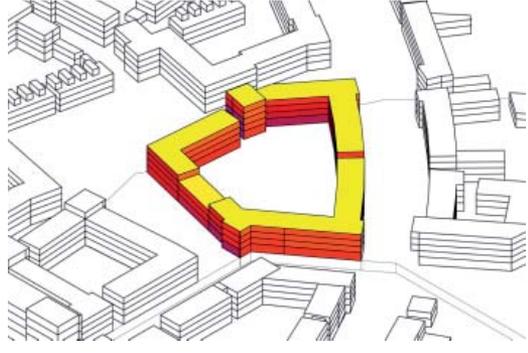
The used method in the cases of both cities Malmö and Lund can be seen in Figure 6. The building blocks were simulated in Ecotect directly to get numerical results. In order to get a better integration in the daily workflow of designers, the graphical output of the annual solar radiation analysis was performed by connecting the CAAD program Rhinoceros through the GECO plug-in to Ecotect[21]. The method consists of five steps: 1) a design alternative is developed and drawn in 3D, 2) the annual solar insolation is simulated, 3a and 3b) by setting a certain threshold (in this case 650 kWh/m<sup>2</sup>/year), a certain part of the building envelope is selected as the most appropriate for harvesting solar. This is both visualised graphically and numerically. Step 4 is the evaluating phase: does the design alternative live up to the expectations? If not, than another design alternative is performed and will go through step 1-3, otherwise the process goes on to step 5. In step 5, both the graphical and numerical output of the solar potential is given to the architects who will design the building in detail. It is important that this is the knowledge transfer is done properly so that this information is not lost in later design phases. In such a way, design alternatives can be compared with each other for their solar potential and performance.

However, certain issues need to be addressed first so the method can become more versatile:

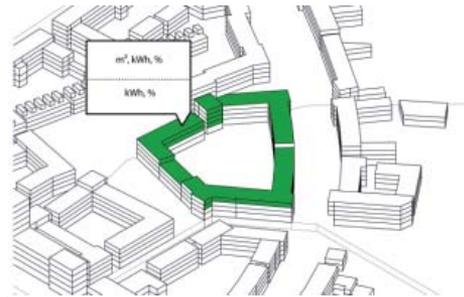
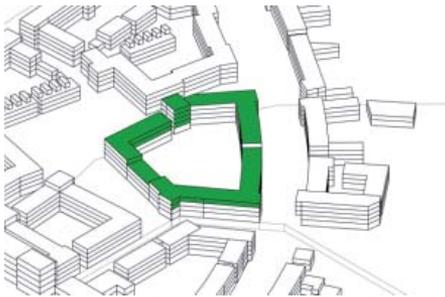
- Solar Thermal needs to be implemented in the method. This is a rather simple adaptation of the calculation method. By doing so, the tool can take into account both DHW / heat, and electricity.
- Giving an overview of the costs and benefits of implementing active solar harvesting would provide an extra factor to take decisions upon.
- The threshold value should be discussed. With the threshold of 650 kWh/m<sup>2</sup>/year as it is taken now, parts of the facades and roofs were selected. If the threshold was instead set much higher, only roof areas would be valid for placing PV cells.



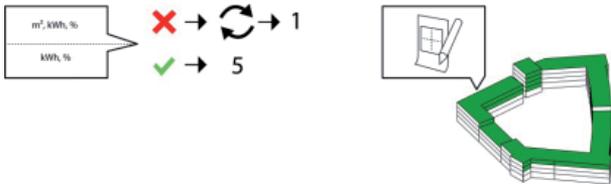
Step 1. Design alternative is developed, building is available in 3D.



Step 2. A simulation is run for the annual solar insolation



Step 3. All surfaces above a certain threshold are shown visually and numerically



Step 4 and 5. If the design alternative performed as planned, information is given to the architects. Otherwise, back to step 1.

Figure 6. Visualisation of a possible working method for urban planning

#### 4. Conclusions

The results of the simulations done in this study show that taking solar energy into account when designing new urban district can provide a significant contribution to the local production of renewable energy. Also, solar zoning [22] can contribute to solar access for solar energy in denser cities.

Certain designs of building blocks performed better than others in the simulations, especially when the blocks were surrounded by a dense built environment. When the plot ratio / FSI was 1, almost all design options were able to meet the energy need with energy produced by solar energy. When the FSI was increased, building blocks were not able to meet all the energy need with locally produced energy. In one case, the solar potential decreased by 75% when it was placed in dense built environment, which meant that the electricity coverage of this design was very low.

Urban planning is a process in which many factors play a role. Solar energy is just one of these components which urban planners have to take into account. Urban planners should be informed about the consequences of building blocks' layout on the solar potential. In an ideal situation, one actor in the design process should perform the simulations and calculations regarding the solar potential as described in this article. This actor could be an external consultant, an urban planner or an architect. The further in the design process, the more detailed the solar potential analysis can be done. Important issues in these analysis are: the production of the active solar systems (kWh), the production over the year, the ratio between PV and ST, architectural integration issues (colour, texture, dimensions) etc.

It is also important that real estate developers are well-informed about the latest technology and prices, since they are a very important factor in the decision process. In the two cities of Lund and Malmö, the urban planning department has set up meetings with real estate developers to talk about sustainability issues, of which solar energy is an important contributor.

In general, the production of electricity did not meet the electricity need. In this study, only the electricity need was taken into account, not the heat / DHW need. If those two components will be taken into account, the question whether to produce heat or electricity on which places in the building will become very actual. Furthermore, the fact that the annual solar energy production is not able to meet the energy need of buildings in cities leads to the issue if it is right to force future all buildings to generate all their energy locally within cities. Another conflict of using the whole roof is the competition with the green roofs.

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# Article II



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## The design process known as IDP: a discussion

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### Abstract

The Integrated Design Process (IDP) was developed to streamline the design process of (solar integrated) low-energy buildings. One of the biggest differences with the traditional design process is the involvement of engineers and other consultants right from the early design stage. Although the IDP has been fully developed in theory with clear and general descriptions, the practical application of the IDP is, however, often far from smooth. In this article, some critical issues of the IDP are discussed, based on literature review, interviews with architects, and experiences with local and international projects, with the hope that these experiences help improving future design process. The discussed issues are: quantification of actors' input, the education of the IDP in the contemporary university curricula, costs of the IDP, and communication.

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Keywords: design process; IDP; architects; engineers; consultants; communication; low energy buildings

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### 1. Introduction

Future building regulations will require building nearly Zero Energy Buildings (ZEB) in Europe in 2020 [1]. In other countries, similar plans are on their way. Solar energy will contribute significantly both to the energy reduction and production necessary in a nearly ZEB, with both the active (PVs and Solar Thermal) and passive use of solar energy, such as heat and daylight. The design of such ZEB buildings can be a rather complex endeavour; it requires a higher level of technical knowledge from the very start of the design process.

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The integrated Design Process (IDP) is ‘a procedure considering and optimising the building as an entire system including its technical equipment and surroundings and for the whole lifespan. This can be reached when all actors of the project cooperate across disciplines and agree on far-reaching decisions jointly from the beginning’ [2]. A similar definition of the IDP was formulated by Busby et al.: ‘In general, the integrated design process is an approach to building design that seeks to achieve high performance on a wide variety of well-defined environmental and social goals while staying within budgetary and scheduling constraints. It relies upon a multidisciplinary and collaborative team whose members make decisions together based on a shared vision and a holistic understanding of the project’ [3]. The IDP has proven to be very effective in producing high-performance and environmentally-friendly building [2-7]. In addition, the IDP optimises project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction [8]. These advantages of the IDP are mainly the result of the shift of the work peak: more is done in earlier stages compared to the traditional processes, reducing the costs of design changes and increasing the ability to change the design (Figure 1).

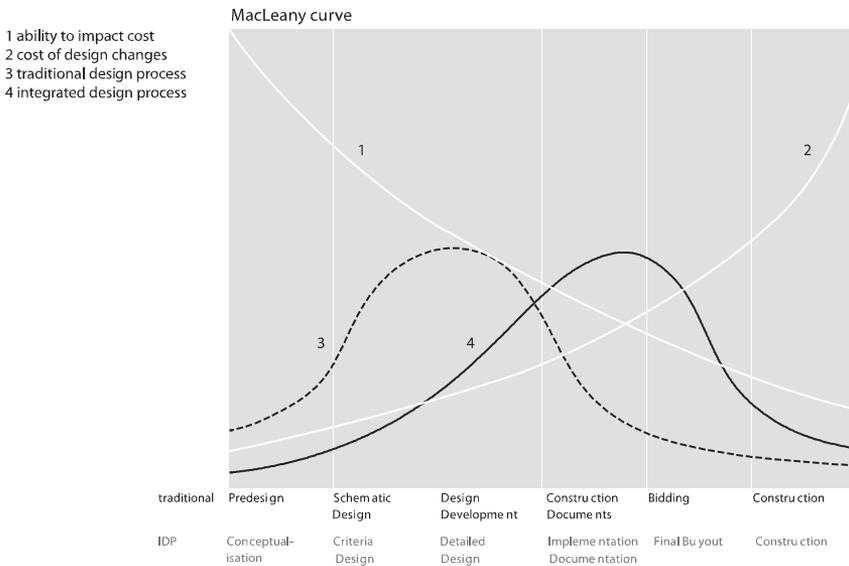


Figure 1. Macleamy curve showing both the traditional process and the IDP [8].

While the IDP is, in theory, a rather clear and uniform process, the practical execution is often far from that. The discrepancy between theory and practice could be due to the conditions of the specific design process, such as the type of client, type of building, the structure of the design team etc. This article identifies and discusses issues which architects and other actors have been encountering while designing according to the IDP, in the hope that it may start a broader exchange of opinions and, thus, help improve future IDP ventures.

## 2. Sources

The discussion in this article is based on the following sources: 1) literature review, 2) interviews with architects, 3) experiences based on the local application of the IDP, and 4) different case studies of IEA-SHC Task 41: Solar Energy and Architecture. The literature review consists of the literature from the early 2000s until today. The second source is interviews done with architects on the design processes of solar integrated architecture during 2010-2011, in total: 12 in Sweden, 2 in Norway, and 7 in Denmark (Quotes of the interviews are displayed in *italic*). The interviews with only the Swedish architects have been discussed in an earlier publication [9], showing, among other things, that good teamwork was found to be crucial in the design process. Interviews were semi-structured and the analysis was done following Glaser and Strauss' grounded theory and with the help of the program QSR NVivo. The third source is the experiences of 'The Sustainable Urbanism Initiative' team from Toronto, which participated in the Equilibrium House competition organised by Canada Mortgage and Housing Corporation during 2006-2007, where multidisciplinary team of architects and engineers (mostly university professors and graduate students of architecture, building science and mechanical engineering) and consultants worked together to design a Net Zero Energy house in an IDP that was also well documented throughout the process [10]. The last source is experiences which have come forward in IEA-SHC Task 41: Solar Energy and Architecture, the first IEA Task that has been looking into solar design from the architects' point of view in a three years long project that included researchers and practitioners from 14 participating countries. Its goals included identifying barriers that architects are facing related to solar design, helping achieving high quality architecture for buildings that integrate solar energy systems, as well as improving the qualifications of the architects [11].

## 3. Discussion

Mapping a design process is a theoretical analysis tool, providing an overview of actors and activities during time. The Integrated Design Process has been mapped in several studies. In Figure 2, Table 1, and Table 2, three maps of the IDP are shown according to three different studies [2-3, 8]. The first map, described by IEA-SHC Task 23 (Figure 2) focused more on the design process itself, while the other two, one by Peter Busby et al, and the other by American Institute of Architects (AIA), also included the other stages of the project, such as construction phase, and even post-occupancy-stage (Table 1, Table 2). Interestingly, all three maps give slightly different categories which confirms the fact that it can be very hard to frame and pinpoint the design process. Besides referring to particular stages of the project in a different manner, the mentioned studies also differ on assigning a particular task(s) to each participant / actor in the process.

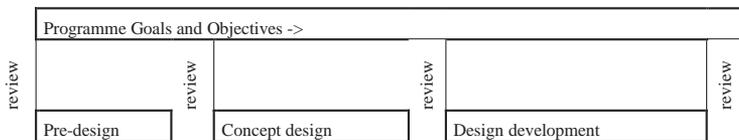


Figure 2. Division of the design process into three phases (after Löhnert et al. [2])

Table 1: Set of phases of the IPD (after Busby et al. [3]).

Phase 1:	Pre Design
Phase 2:	Schematic Design
Phase 3:	Design Development
Phase 4:	Construction Documentation
Phase 5:	Bidding, Construction, Commissioning
Phase 6:	Building Operation
Phase 7:	Post-Occupancy

Table 2: Map of the IDP (after AIA California Council [8])

Design phase / actor	Conceptualisation	Criteria design	Detailed Design	Implementation documents	Final Buyout	Construction	Closeout
Agency							
Owner							
Designer							
Design consultant							
Constructors							
Trade constructors							

While maps of the IDP can be useful to get an insight in what activities are done in which phases and which actors are involved, the reviewed Integrated Design Process documents provide only very broad and general guidelines so that they can be applied in various situations; framing the process more firmly would most probably impose limitations to it [7]. However, such ‘loose description’ can also be counterproductive and hinder the process itself as it may be difficult to manage expectations and output from various actors.

Interviews with Scandinavian architects, as well as experiences from IEA-SHC Task 41, have indicated that the following issues of the IDP are vulnerable and therefore discussed here: actors vs. activities, costs, competitions, education, and communication.

### 3.1. Actors versus activities

The role of different actors in the design process is described in the majority of literature, agreeing that all actors need to be involved from the beginning [2, 5, 8, 12]. This was also experienced by the interviewed architects who had gone through an IDP. For example, in the description given by IEA-SHC Task 23, it is stated that in the true IDP settings, the architect becomes a team leader rather than the sole form-giver, mechanical and electrical engineers take on active roles from the early design stages, and the team always includes an energy specialist[2]. By working in such settings after some times, the architect gains deeper knowledge of technical solutions while the engineers simultaneously gain insight in the architectural design [2]. Getting to know more about each other’s work can certainly deepen the understanding between different actors in the process as well as it improve the communication between them, thus improving the IDP process itself and hopefully bring final solutions sooner. The interviewed architects experienced working with engineers very helpful.

*You need to have generalists who can make people talk together, have the overview, but [you] also need to have competent specialists...[...] so: both the creative architect and the competent energy engineer. If you only have specialists, you have no project. If you only have generalists, you are not cutting-edge enough. You need to have both in the right combination. And with this you do a very good project. (Architect #13)*

Another way of describing the design process is by focussing on activities rather than on actors. Biesbroeck et al. [13] assigned tasks in the early design process of Net Zero Energy Buildings, but they were not assigned to a specific expert. They only provided a domain, like 'Architecture', 'Building Physics', making it able for some experts to perform multiple tasks. This could especially be helpful in smaller-scale building design processes, where resources for hiring many disciplines might be limited.

Interestingly, the two ways of describing the process (actors *versus* activities) might contradict each other. For example, an architect might have been able to build up enough knowledge to go through the early phase of the IDP without the involvement of an engineer, although the need of the early involvement of the engineer is seen as an important part of the IDP.

*I have been involved in previous [research] on the development of the passive house concept. This gave me the opportunity to do a lot in the first phase without having to involve many others. (Architect #1)*

It might be costly to have both an experienced architect *and* an external engineer involved with more or less the same knowledge required for the early design phase, especially in smaller and less complex projects. On the other hand, the disadvantage of not having the engineer involved from the beginning is that the engineer does not get 'attached' to the project, or does not fully participate in defining and, thus, sharing the common goal with other actors in the process, which is one of the essential premises in the IDP. The involvement of (external) engineers in the early design phases is especially needed in large-scale projects or in complex environments since it is harder to reach low-energy architecture in these cases than in a stand-alone house.

Another important aspect is the quantification of actors' input. The majority of interviewed architects answered that their design process was according to the IDP, but this claim was difficult to judge or verify. Even though all actors were involved from the beginning, there might be a big difference in their contribution to the common goal of designing a low-energy / nearly zero energy building. According to the IEA-SHC Task 23, "all potential team members should be screened for their willingness and interest in following the process and in crossing normal professional boundaries" [2], but obviously, it is hard to make this willingness measurable. In those design processes discussed in the interviews, architects experienced that sometimes it was hard to achieve common goals with all actors, since everybody had their own speciality. In other cases, conducting workshops contributed to reach common goals and to gain an interest amongst all actors. Defining common goal(s) usually includes quantitative / measurable outcomes. In one case, however, the architect was recalling that the interdisciplinary team felt that defining mere quantitative goal, a Net Zero House, "didn't feel inspiring enough". Everyone's enthusiasm was awakened, however, when someone started telling a story, a fictional scenario that described first-hand experience and quality of life of a family after living in this house for 20 years, children growing up and parents growing old while enjoying comfort, natural light in every room and being aware that "they didn't take more from the environment than they gave back". Somehow, every participant found a way to relate to this story on a personal level, so it became a very strong common goal that kept everyone not only focused, but also very passionate about the project [14].

In some cases, on the other hand, clearly described performance goals were determined for each design stage, but this time the tasks were specifically assigned to certain actors. A major disadvantage of this specification is the introduction of an abundance of specialists who might be guarding their own *territory*; making it harder to collaborate. An experience of one interviewed architect reveals quite a frustration with their team-mates' highly specialised roles:

*I mean it is a problem, they are so specialised that they don't think of the building as a whole. They think of the air system as one part and the construction as one part. They divide everything. They don't have the ability to balance all these specialities. (Architect #15)*

An advantage is, on the other hand, that the issue of responsibility is better defined when every team member is legally responsible for his/her actions. Securing legal responsibility is important in the design process for all actors since actions in the design process might get legal consequences in possible lawsuits, as well as it is important for professional insurances.

### 3.2. Payment structure and costs of the IDP

The Integrated Design Process has a different distribution of work done during the design process, since the work peak is shifted to earlier phases. However, payment structures were often still adapted to the traditional design process.

If the client only approaches an architect for the design of a building, then it is up to the architect to decide how to work. Some clients might however be aware of the existence of the IDP as an option or the architect can inform the client about the IDP. What is important for the client to know is that the same amount of work will be done, but not at the same time frame as in the traditional process. Another important point to add in convincing the client is the fact that by using the IDP as a model for the design process, the final result will probably end up being better: for example, the energy use of a building can become much lower compared to those designed through traditional processes, which is advantageous for the client in the long run.

### 3.3. Competitions

Many architectural offices participate nowadays in open or invited competitions besides their normal commissions. In Europe, EU directives have led to competitions being used as a means for clients to purchase architectural services [15]. However, the jury and / or client how focussed on the price rather than on the quality of the service [16]. The uncertainty of proceeding to the next competition round makes that architectural offices do not automatically work according to the IDP. That means that architects might not work together with engineers, even though crucial decisions on the architecture of the buildings (and thus indirectly energy performance) are made in the competition phase. Some offices build up an extensive technical knowledge in-house, which requires an investment and might not always be feasible. When participating in invited competitions, a compensation for the labour of the design team might be provided, something which is not in the case of open competitions.

Setting clear, measurable, energy performance goals for the buildings in the competition brief might put more focus on the consequences of architectural decisions, but it will not solve the lack of compensation for performing such simulations which are needed to be able to provide the energy performance of the building.

### 3.4 Education

In many architecture and engineering schools, to the best knowledge to the authors, the theory and practice of the Integrated Design Process is not included in the basic curriculum; possibly a review can be done in the near future to verify this.

While it is impossible to verify whether this statement is accurate or not, its significance lays in a fact that in some cases the actors enter the process with strong preconceptions about the other professions; this

surely cannot offer a good start to an open and fruitful collaboration, and can contribute to misunderstandings and the lack of communications between actors in the IDP.

Architecture students are often taught to design within the framework of design studios, but hardly ever with those actors which they will work together later throughout their carrier, such as engineers. At some universities, however, in recent years, projects are set up in which students from multiple disciplines work together in order to design low-energy buildings. An example is the Virginia Polytechnic Institute which decided to join the Solar Decathlon with architecture, industrial and interior design, and mechanical and electrical engineering students [17]; actually, in order to succeed, all Solar Decathlon participating teams end up being multi-disciplinary. Another example are applied, multi-disciplinary projects done at the Eindhoven University of Technology [18]. There, architecture and engineering students work together in a workshop environment, where they have to perform realistic assignments together. The educational program was supported by the Institute of Dutch Architects and Consulting engineers, who applied this setup later in their educational program for practitioners. At Ryerson University in Toronto, students in both Architecture and Building Science graduate programs have a requirement to do a so-called Collaborative Workshop, lasting at least 50 hours, where they have to find a project to work on with colleagues and professionals from other disciplines [19]. In the majority of cases, students choose to do a design competition. Although the IDP is not specifically required, very often students do self-organise in a process that greatly resembles IDP. However, as this is not academically formalised, it cannot be concluded that they are actually taught IDP.

Architecture students, as well as all other disciplines, like engineers, could profit from a good collaboration. This is a good reason to include theory about design processes in the curriculum. Reasons behind the lack of such courses on the design process and collaboration might be that such processes are hard to theorise, as well as that it might be hard to place such knowledge into one institution.

Another important aspect within the context of the education of the IDP is the new role of the architect. By gaining the role of leading the design team, the architect should not only longer have design competences, but also management competences. Managing design teams might not be included in the curriculum either.

Architectural associations however do provide extra courses on design processes and the role of architects. Two examples of such courses are given by the RIBA: Continuing professional development courses [20] and the AIA: Continuing education courses [21]. In this way, practising architect can gain more knowledge about the design process as well as management knowledge when this is required.

### *3.5 Communication*

The IDP theory notices that communication between actors is crucial [12, 22], but how is this communication managed? Communication problems between architects and engineers, but also between engineers and engineers, might lead to inefficiency. When more actors get involved, an effective communication gets more crucial. Within the guidelines of IEA-SHC Task 23, it is stated that “communication competence, openness and interdisciplinary team ability must be secured for all design team members” [2], although it is not described how this competence should be secured.



Figure 3: The Sustainable Urban Initiative team's IDP design charrette for 2007 EQuilibrium House competition organised by Canada Mortgage and Housing Corporation [6]

During the interviews, architects experienced that they learnt a lot from working with engineers, but that it sometimes also had led to difficulties [9]. Too many specialised actors needed to work together, resulting in many actors trying to guard their own speciality. Many architects took up the workshop as a good start for the design process and a good example of communication with many actors. In such “kick-off” workshop in the early design phase, the nature of the integrated design process will be explained and it will support the team spirit [2]. In some cases of the interviewed architects, the architects were in minority in such workshops, leading to the fact that architects need to be competent to deal with such situations.

*So we had all the largest engineer companies in Denmark sitting at one table. When we started discussing energy and technical solutions, we had workshop with 30 to 40 engineers. I think you need to be a bit of an “archineer”. In many ways you need to know some things about technical systems. You have to find the interest in listening to these things. Also, you have to come up with a solution within the architectural concept. (Architect #16)*

The role of the client is also very important in the IDP. If the client chooses for this kind of design process, they need to be open for it as well as it requires another way of communication of all actors. Wishes of the client need to be expressed early, as well as the design team needs to give clear feedback to the client. It is especially important to visualise how certain design alternatives are chosen based on their effect on energy performance. Only in such a way, the energy performance becomes a clear decision factor.

### 3. Conclusions

It is very positive that the IDP has found its way to the architect's office, but there are some issues which need to be dealt with in order to exploit the process to the maximum of its potentials. These issues are actors vs. activities, costs, competitions, education, and communication.

Many models of the IDP are kept very generic in order to highlight the importance rather than serving as a custom-made guideline for every design process. For every building, the design teams needs to be custom-made according to specific demands of the building. A continuation of the design team for several projects is preferable, but in reality this might not be the case.

The early design phase is a very crucial phase for the success of the IDP. Since traditional roles and methods are not effective anymore when designing low-energy architecture, all actors need to be actively engaged from the beginning. This implies that the client needs to demand that the design process is done according to the model of the IDP, engineers need to be involved earlier in the beginning, and architects cannot make all decisions themselves anymore. Structuring the design process in this way, all decisions taken are done by agreement of all actors. A start-up workshop was seen by architects as an important event to agree on common goals and as a way to build up a solid design team. Getting actors engaged in the design process is an important condition for results in the design process, but at the same time a factor which might be hard to achieve.

By embedding theory of the design process as well as setting up interdisciplinary projects / courses, future architects can get acquainted with collaborating with other actors. However, current curricula at architecture schools do often not deal with the design process; neither does it include management courses.

The shift from the traditional design process to the Integrated Design Process has been started, but need to gain more strength. If the issues which are discussed in this article are taken up by the profession, other actors as well as the schools, are solved, then the IDP might start to become the standard design process.

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## Article III



# Adequacy of current design tools and methods for solar architecture – results of IEA-SHC Task 41’s international survey

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**ABSTRACT:** *The International Energy Agency’s (IEA) Task 41: Solar Energy and Architecture gathers researchers, academics and practicing architects from 14 countries in a project pursuing the objectives to identify and address obstacles that architects are facing in solar design. Part of this three-year project is the development of an international survey -intended for practicing architects- addressing a broad range of issues from passive and active solar design to the availability and adequacy of existing digital tools. This paper presents parts of the results of this international survey related to Task 41 Subtask B: Tools and methods for solar design. The results show that there is still a need to improve tools and methods for architects such as increased support needed for decision-making and for solar design in CAAD tools. The results also state that architects’ skills with regards to solar design in tools are ‘poor’ or ‘very poor’. Furthermore, results indicate that decision-making for the integration of solar technologies in the conceptual phase is mainly handled by the architects alone. Finally, the results show that tools need to be simpler, that the interoperability between software needs to be improved, that tools should provide key data about solar energy aspects as well as explicit feedback to the architect, and that tools need a better visualisation especially for active solar energy systems.*

*Keywords:* design methods, digital tools, CAAD, visualization, simulation, solar architecture, survey, early design phase

## 1. INTRODUCTION

The amount of solar energy reaching the surface of the Earth in one year is vast: it is about twice as much as will ever be obtained from all of the Earth’s non-renewable resources of coal, oil, natural gas, and mined uranium combined [1]. Also, more solar energy reaches the surface of the Earth in one hour than the total amount of energy used by humans in one year [2]. In many locations, the solar energy incident on the roof of a typical home exceeds by far its energy consumption; there is, therefore, the potential for a building to achieve net zero energy consumption if the utilization of solar energy to produce electricity, useful heat and daylight is optimized [3]. In spite of these facts, a large portion of the potential to utilize solar energy still remains unused [4]. According to the International Energy Agency, this is caused by several factors:

- 1) economic factors,
- 2) lack of technical knowledge,
- 3) reluctance to use “new” technologies, and
- 4) architectural (aesthetic) factors [5].

The integration of solar energy systems and technologies in existing and new buildings could be greatly facilitated in the future if architects are informed, aware and engaged in the development of solar energy in buildings. Architects should also be conscious of the potential, limitations and characteristics of solar energy systems. Architects have a significant role to play in the development of solar energy systems and technologies in buildings

because they are primarily responsible for early design phase (EDP) decisions (such as orientation, shape, size of openings). EDP decisions have the greatest impact on the durability and performance of any building project [6].

### 1.1. Task 41: Solar Energy and Architecture

Task 41: Solar Energy and Architecture is gathering researchers and practitioners from 14 countries in a significant project, which will identify obstacles for solar design while providing recommendations and support for the implementation of solar technologies and strategies in buildings. The ultimate goal of Task 41 is to accelerate the development of high quality solar architecture. This task is focused mainly on the architectural profession, as a key factor in the future evolution and implementation of solar building design in existing and new buildings. The main objectives of Task 41 are:

- 1) to support the development of high quality architecture for buildings integrating solar energy systems and technologies, and
- 2) to improve the qualifications of architects, communications skills and interactions between building professionals, manufacturers and clients.

To achieve these objectives, the work plan of Task 41 is organised according to three main subtasks: A, B and C. Subtask A concentrates on architectural quality criteria; guidelines for architects and product developers by technology and

application for new products. Subtask B focuses on guidelines for the development of methods and tools with emphasis on tools for EDP as well as tools for the evaluation of the integration quality of various solar technologies. Lastly, Subtask C concerns integration concepts and examples, and derived guidelines for architects.

This article presents some results of Subtask B, which pursues the following specific objectives:

- 3) to achieve an inventory (state-of-the-art) of existing methods and tools that architects currently use at EDP when designing buildings integrating active and/or passive solar components,
- 4) to identify current barriers preventing architects from using existing methods and tools for solar building design, and
- 5) to identify important needs and criteria for new or adapted methods and tools to support architectural design and integration of solar components at EDP.

The first objective (State-of-the-art) has already been reached and the results have been published as Report T.41.B.1 titled *State-of-the-Art Of Digital Tools Used by Architects for Solar Design* [7].

## 2. LITERATURE REVIEW

A literature review showed that computer-aided architectural design software is adequate to support architects during the design process and to improve their skills [8]. Previous studies also indicate that design teams use available tools in different ways during the design process and a lack of tools for early design was identified [9]. It was shown that design team used computer tools for around 25% of their work in the early stages of the design. On the other hand, it showed that the design units indicated that 100% of their tasks were computerised. Therefore, it appears that currently, the software tools are primarily developed for advanced design stages.

## 3. METHOD

### 3.1. International survey

The web-based survey was conducted internationally including 14 countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, South Korea, Norway, Portugal, Spain, Sweden and Switzerland) and was translated into eight languages. The translations were made by the researchers and professionals involved in Task 41. The survey was generated with the program *Questionform* [10] and was launched on the Internet by each national coordinator of IEA Task 41. Data collection lasted from May 3<sup>rd</sup>, 2010 to October 25<sup>th</sup>, 2010.

The focus group of this survey consisted of practicing architects. Within Task 41, one national coordinator for the survey was appointed; all of them used a different approach for reaching the focus group. Examples include: creating national

databases of contacts through professional associations and public directories, through publishing survey links in architectural publications, newsletters and on websites.

### 3.2. Questionnaire

The questions and layout of the survey were developed during the IEA Task 41 international meetings with the collaboration of all researchers and practitioners. The IEA Task 41 team created two surveys: one relative to Subtask A objectives, and the other relative to Subtask B objectives. Both surveys included the same first two questions which aimed to determine the knowledge and the awareness of respondents about solar architecture. The survey related to Subtask B consisted of 22 questions including three question types: multiple selections of specific categories, a single selection of a specific category, and free text. The multiple selection questions showed a list of the most expected answers. Some of them also allowed respondents to specify other answers.

### 3.3. Response rate

A total of 223 completed questionnaires were analysed out of 616 received for Subtask B survey. One limitation of this survey is the fact that respondents are most likely to be those who are interested in the issue of solar energy and who either have previous experience with integrating solar energy in architecture or willing to do so in the future. This, in itself, constitutes a bias of the research. Also, the low response rate for the survey generally shows that there is a low interest by architects for this topic, which bears consequences for the future development of solar energy in buildings. It may also indicate that architects have little availability for answering surveys. For example, around 1050 emails were sent in Canada, resulting in only 30 fully completed surveys. The response rate for Canada was thus only around 3%, which is rather low.

### 3.4. Data analysis

The data was collected and analysed by the Canadian Subtask B team.

Detailed data analysis of all responses will be presented in the Report T.41.B.2 titled *International survey about digital tools used by architects for solar design* which is part of Task 41 official publications, and will be available in March 2011 on the IEA Task 41 web site. The data analysis does not include a statistical analysis to test and prove the sample representation of the population. Therefore, the survey sample and findings are not statistically representative and were analysed statistically. However, the results outline patterns and tendencies among the design community of architects internationally.

## 4. SURVEY FINDINGS

### 4.1. Description of respondents

A series of questions at the end of the questionnaire aimed to establish the participant's

profile. These questions included the following aspects: description and size of architectural firm, scope of architectural practice, type of building projects designed, project delivery method, year of birth, gender, profession (architect, engineer, physicist or other) and professional experience. Mostly, the results permitted to describe the general profile of respondents and indicated that most often, the respondents:

- worked in small firms;
- were active mainly nationally, but sometimes collaborated in international building projects;
- worked with newly-built projects and building renovations in similar proportions;
- worked on residential and commercial building projects rather than institutional, governmental or industrial buildings;
- used a traditional project delivery method where the owner has separate contracts with the architect and contractor;
- were males born between 1951 and 1980 with more than 10 years of professional experience.

**4.2. General questions related to energy use**

The first question aimed at determining the importance attributed to solar energy aspects in the architectural practice. The majority (79%, n=177) of respondents considered the use of solar energy in architecture as 'important'. A minority (17%, n=37) of respondents were 'neutral' about solar energy aspects and a few (4%, n=9) rated it as 'unimportant'. None of the respondents answered 'I don't know'.

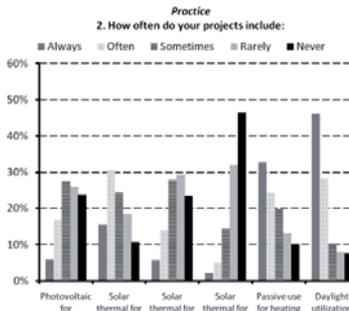


Figure 1: Distribution of answers for question 2 about occurrence of solar energy systems or aspects in current architectural practice (n=223).

The next question (Figure 1) concerned the integration of solar design aspects in the actual architectural practice of respondents. This question concerned 'photovoltaic technologies for electricity', 'solar thermal systems for domestic hot water', 'solar thermal technologies for heating', 'solar thermal technologies for cooling', 'passive use of solar gains for heating', and 'daylight utilization strategies'. The results show that a large proportion of respondents answered that they always included 'passive use of solar gains for heating' (36%, n=79) and 'daylight utilization strategies' (49%, n=109). In contrast, respondents always included 'solar thermal for hot

water' (17%, n=38), 'solar thermal technologies for heating' (5%, n=12), 'photovoltaic technologies for electricity' (5%, n=10) and 'solar thermal technologies for cooling' (2%, n=5).

**4.3 Questions concerning methods**

Question 3 (Figure 2) aimed at determining the moment during the design process, when the professionals first considered the integration of solar energy technologies. Results show that 69% (n=154) of the respondents would consider the integration of solar energy technologies during the 'conceptual phase'. About 26% (n=58) would consider it in the 'preliminary design', 4% (n=9) in the 'detailed design' phase and 1% (n=2) during the 'construction drawings' phase.

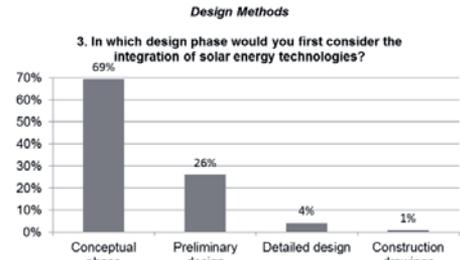


Figure 2: Distribution of answers for question 3 about the moment in the design process when solar energy technologies are first considered (n=223).

Question 4 (Figure 3) aimed at determining the methods used in the design process. Out of 693 selections, 21% (n=144) were marked as 'experiences', 17% (n=120) as 'interactions with the owner', 15% (n=103) as 'collaboration with others'. The next most popular choices were 'design guidelines' (12%, n=86), and 'computer simulations' (9%, n=63). Finally, the least popular selections were 'conception of several propositions' (8%, n=53), 'interactions with future users of the building (public participation)' (7%, n=46), 'rules of thumb' (6%, n=43) and 'expert systems architecture (concept research)' (5%, n=35).

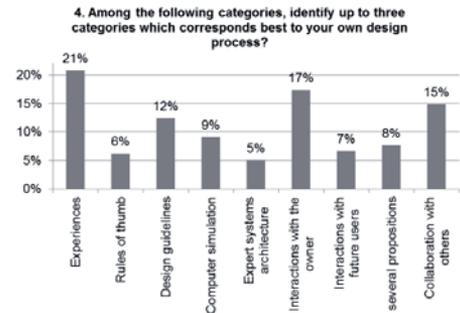


Figure 3: Distribution of answers for question 4 about design process (total number of selections=693).

Two questions aimed at determining how the integration of solar energy technologies was handled in the design process of 1) small projects and 2) large projects. The results show that for both projects sizes, most of the respondents handled the integration of solar energy by themselves. Concerning the EDP, results show that for the 'conceptual phase' and 'preliminary design phase', respondents selected more often 1) 'do it myself', 2) 'consult a colleague (architect) with specific experience', 3) 'involve a building physics/building science specialist', 4) 'involve an external solar energy consultant' and 5) 'involve an internal solar energy consultant'.

The following question was an open-ended question which aimed to identify the need of practitioner-related methods to support the integration of solar systems. Mainly, respondents answered that they would require simple, systematic and clear methods to use in the EDP. They also requested methods that would help take decisions, size technologies, evaluate technologies and involve relationship with contractors, better availability of building physics services, integration of architecture, training to improve knowledge and a catalogue of products available on the market.

The last question concerning methods (Figure 4) aimed at defining which methods were used in the design process. A total of 468 selections were made for this multiple-choice question. Figure 4 shows that a third (32%, n=151) of all selections was related to 'integrated design process-IDP' (collaboration with others professionals in multidisciplinary teams), 26% (n=122) was for 'intuitive design process' (i.e. intuitive decisions made without conscious thought and often refers to the architect's experience), 21% (n=97) for 'participatory design' (interaction between the future users of the building, (i.e. public participation), 18% (n=85) for 'energy-oriented design' (i.e. practicing sustainability with calculator and computer simulations) and 3% (n=13) was for 'other' methods.

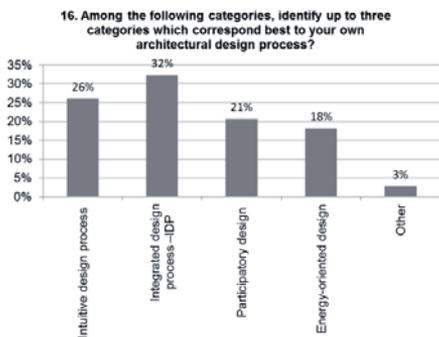


Figure 4: Distribution of answers for question 16 'Among the following categories, identify up to three categories which correspond best to your own architectural design process?' (n=223).

#### 4.4 Questions concerning tools

Question 7 (Figure 5) aimed to identify the current skills of respondents with different tools for solar design. Respondents had to rate their skills concerning four types of tools: 'graphical solar design methods' (i.e. solar charts), 'CAAD (computer aided architectural design) programs', 'solar design tools included in the CAAD programs you currently use' and 'advanced solar or energy simulation tools'. Figure 5 shows that respondents had more skills (very advanced or advanced) with CAAD than all the other tools, but they did not really use solar design tools included in the CAAD programs (31%, n=69 considered their skills as 'poor' and 27%, n=60 as 'very poor').

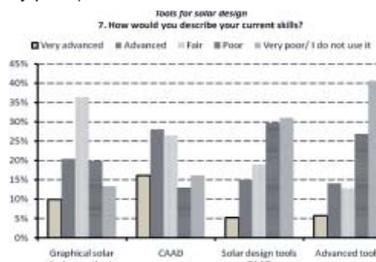


Figure 5: Distribution of answers for question 7 about the skills with the use of different tools (n=223).

Question 8 aimed to determine what software are used by respondents in their current architectural practice and at which phase of the design process these software are used. The software included in the choice of answers were selected among the ones inventoried in the Report T.41.B.1 *State-of-the-art of digital tools for solar design used by architects* [7]. These software were classified according to three categories: Computer-aided architectural design (CAAD), visualization and simulation tools. The results show that these three categories are used in all stages of building projects; 'conceptual phase', 'preliminary design phase', 'detailed design phase' and 'construction drawings phase'. Also, the results show that AutoCAD, Google SketchUp, Revit Architecture, ArchiCAD, Vectorworks and 3ds Max were the CAAD tools most often used by architects, all design phases combined. Concerning visualization tools, the most popular tools, all along the design process, were V-Ray, Arltantis, Renderworks, Maxwell Render and Mental Ray. For simulation tools, the most popular tools were Ecotect, RETScreen, Radiance, PV syst, Polysun, and eQUEST.

Question 9 aimed to determine which factors influence the choice of design tools for professionals. The answers indicated that 'user-friendly design interface', 'cost', 'simulation capacity' and 'interoperability with other software' were more important than 'availability of scripting feature', 'availability of plug-in(s)', 'quality of output (images)' and '3D interface'.

The next question aimed to evaluate the level of satisfaction of respondents concerning the computer

tools they currently use. The software included in the choice of answers was the same as question 8. Out of 565 selections, most respondent were 'neutral' (40%, n=226) and 'satisfied' (31%, n=177) with the tools. Only 10% (n=58) were 'very satisfied', 12% (n=66) were 'dissatisfied', and 7% (n=38) 'very dissatisfied'.

The following question (Figure 6) aimed to identify the barriers to the use of solar design tools. A total of 558 selections were made for this multiple-choices question. Figure 6 shows that the most popular selections for this question were 'tools are too complex; high learning curve' (19%, n=105), 'tools are too expensive' (14%, n=80), 'using the tools takes too much time' (11%, n=62) and 'tools are not integrated in our CAAD software' (12%, n=66). Three choices were selected less often which are 'tools are not supporting the conceptual design', 'tools are too systemic', and 'tools are not integrated in our normal workflow'. Least selected were 'tools are too simplistic', 'I don't know/not applicable' and 'other' barriers.

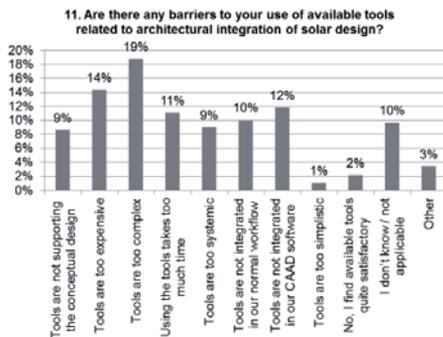


Figure 6: Distribution of answers for question 11 about barriers related to the use of the tools for the architectural integration of solar design (total number of selections=558).

Question 12 (Figure 7) aimed to identify the needs of practitioners related to tools to support the integration of solar architecture. For the 'conceptual phase' and 'preliminary phase', most of the selections were for 1) 'improved tools for preliminary sizing of solar energy systems', 2) 'improved tools for providing key data (number) about solar energy', 3) 'tools that provide explicit feedback' and 4) 'improved tools for visualization'. Concerning the 'detailed design phase' and 'construction phase', most selections concerned 'improved tools for preliminary sizing of solar energy systems' and 'improved tools for providing key data (number) about solar energy'.

The last question on tools was an open-ended question aiming to get the personal opinion of respondents about the availability of tools and their use. The results indicate that respondents requested simple, effective and intuitive tools to be available to use in the EDP. They want tools that:

- have more interoperability;
- are more general and easy to learn;
- calculate quantitative outputs;

- quickly assess optimum building specifications (orientation, thermal mass, thermal inertia, solar use, size panels, etc.);
- integrate shadows;
- perform insolation analysis and exterior temperature;
- combine solar energy with other sources of energy;
- involve 3D models;
- generate complete thermal analysis (hourly, monthly and annual);
- generate relevant outputs and
- involve economic analysis.

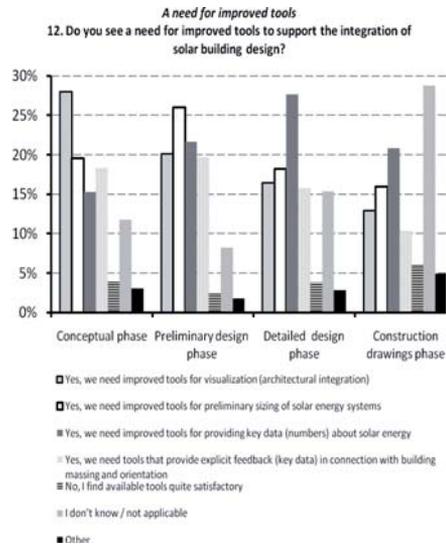


Figure 7: Distribution of answers for question 12 about needs for improved tools to support solar building design (total number of selections=1 221).

## 5. CONCLUSION

The results of this international survey show that methods and tools for solar architecture are not yet well-defined and suitable for architects. The importance to adapt methods and tools to support architectural design and integration of solar components -in order to accelerate the development of solar energy in architecture- is recognised without a doubt. Results of this survey identify important needs and criteria for methods and tools to support architectural design and integration of solar components at EDP (early design phase). The results also emphasize that the early design phase (EDP) is crucial for the integration of solar systems and strategies, both for passive and active solar energy systems.

The international survey shows that the issue of solar energy use in buildings was actually important for respondents. Most of them already used some technologies, especially passive strategies such as the use of solar gains for heating and daylight utilization. The results indicate that the traditional approach (project delivery method) was still used by

architects and past research have shown that this is not providing the best results [11].

Concerning methods, results indicate that in the majority of cases, architects handled solar integration by themselves. In some cases, in the EDP, they consulted a colleague architect with specific experience, a building science specialist, or an external and internal solar energy consultant. In addition, results show that respondents used mostly 'integrated design process-IDP' which means that respondents are involved with other professionals, such as engineers and experts, in multidisciplinary teams. They also used 'intuitive design process' which refer to their own experiences. Lastly, 'energy-oriented design' method is used, which indicates that the interest about solar energy utilization is real. The respondents' design method was often based on experiences, interactions with the owner, collaboration with others, design guidelines and computer simulations. These design methods were more used than the utilization of several propositions to evaluate possibilities, interactions with future users of the building, rules of thumb and expert systems architecture. Current barriers were that methods were unsystematic, did not support decision-making process in satisfactory manner and did not improve much knowledge about solar technologies.

When considering tools for solar design, the results show that current obstacles architects are facing lay in additional skills needed for solar design in CAAD. As for the advanced tools, the obstacles were identified as: complexity, costs of programs, time needed to master advanced software and the lack of interoperability with other software commonly used. As a frequency of use, most of respondents used AutoCAD, Google SketchUp, Revit Architecture, ArchiCAD and 3ds Max as CAAD tools, V-Ray, Artlantis, Renderworks, Maxwell Render and LightWave as visualization tools and Ecotect, RETScreen, Radiance, PV syst, Polysun, bSol and PV SOL as simulation tools. For the EDP, respondents expressed the need for improved tools for preliminary sizing of solar energy systems, providing key data about solar energy output, providing explicit feedback and allow visualization of architectural integration quality. Since EDP is a highly intuitive, iterative process, an appropriate EDP tool should allow changes on the building overall volume, geometry, or orientation with only a mouse click, and provide direct feedback related to solar aspects to the architect.

The detailed results of the survey will be presented as IEA Task 41: Report T.41.B.2. From this report, clear guidelines for tool developers will be written. It is expected that this will initiate communication between tool developers and the architectural community in order to stimulate the development of adequate and improved digital tools.

### 5.1 Limitations

Although sent out through many channels, the response rate for this survey was low and can be seen as the main limitation of this survey. It shows that there is a low interest amongst architects for this topic. Also, there is a risk that the respondents are

those who are interested in the issue of solar energy and this in itself constitutes an important bias of this research.

## 6. ACKNOWLEDGEMENTS

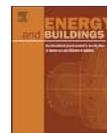
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## Article IV





## Tools and methods used by architects for solar design

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### ABSTRACT

Architects have a key role to play when it comes to the design of future low-energy (solar) buildings. Proper design tools and working methods could help architects in the design process. In order to identify barriers of existing tools and methods for solar design, needs of architects for improved tools, and to gain an insight into architects' methods of working during the design process, an international survey was carried out within the framework of IEA-SHC Task 41-Solar Energy and Architecture, combined with semi-structured interviews. This paper presents an overview of main results of this study.

Both the survey and interviews strongly indicate the need for further development of design tools for solar architecture, focusing on a user-friendly, visual tool that is easily interoperable within current modelling software packages, and which generates clear and meaningful results that are compatible with the existing work flow of the architect. Furthermore, the survey and interviews also indicated a strong awareness about solar aspects among respondents. However, this was combined with a limited use and knowledge of solar energy technologies, suggesting the need for further skill development amongst architects and tool development to accelerate the implementation of these technologies in future buildings and urban fabric.

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### 1. Introduction

Our future built environment needs to be low-energy consuming in order to be resilient to future developments in energy resources and distribution. In several countries, legislation is pushing towards nearly zero energy buildings within a decade or two. In Europe, the recast of the EPBD directive [1] is an example of this legislation. These nearly zero energy buildings will not only need to be energy efficient, they will also need to produce their own energy by the integration of, for instance, passive and active solar energy systems.

Architects have a key role to play in future (solar) low-energy buildings, since passive design is related to architectural decisions already made in the early design phase (EDP). This question was addressed in a recent IEA-SHC programme project titled Solar Energy and Architecture [2]. In the context of Subtasks A and B of this task, an international survey was carried out which was separated in two parts. The Subtask-A survey concerned the integration of solar energy systems in architecture, while the Subtask-B survey was about the adequacy of existing tools and methods for solar design, with emphasis on the early design phase. In this article,

only results of the subtask B survey are discussed. More detailed results of the Subtask-B survey can be found in the IEA-SHC Task 41 report T41.B2 [3]. In addition to the survey, semi-structured interviews were conducted with architects and urban planners who designed solar integrated buildings or urban plans. These results are discussed in the second part of this article.

The objectives of the Subtask-B survey and the interviews were:

1. To identify barriers of existing digital tools and design methods for solar design;
2. To identify the needs of architects for better or improved tools and methods;
3. To gain an in-depth insight into architects' methods of working with design tools and building performance simulation (BPS) programs during the design process.

The design process and the role of BPS tools have been the subject of several studies. In an overview of widely used BPS tools, Crawley et al. [4] noticed that there is no common language on describing what the tools do. This leads to the fact that architects do not necessarily know which tool would fit their working method best.

Likely, Lam et al. [5] showed with a survey amongst building professionals in Singapore that architects did not see the use of simulation tools as a part of their design responsibilities. In parallel, in a survey performed by de Wilde and Voorden [6], the

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majority of responding architects indicated that they did not use specific tools to support energy related aspects in their design process. With the increasingly high demands placed on energy performances of buildings, evidence-based design by validating different design alternatives and choosing the most suitable options from all points of view [7] becomes more important for all actors in the design process, especially in the EDP.

BPS tools can be of great help when validating these different design alternatives. In an article describing a new, prototypical tool, Schlueter and Thesseling [8] noticed that there is a lack of current BPS tools supporting the EDP, and numerous authors agree with this [5,9,10]. Current BPS tools are found not to be 'architect friendly' [9] because they are not compatible with architects' working methods and needs, as well as it is difficult to exchange information between different tools without losing information [11]. It might explain why rules of thumb are still widely used by architects in the EDP because they provide quick and rough estimates on solar energy.

The lack of appropriate tools has been regarded as an opportunity by many researchers to develop new BPS tools which would fit the needs of architects better. Some examples of these are described by Ellis and Matthew [12], Schlueter and Thesseling [8], Yezioro [13], Chlela et al. [14], Peter and Svendsen [15], and Garde et al. [16]. All of them share the common goal of reduced complexity in input, reduced simulation time, while providing a graphical interface rather than a numerical one, which makes it easier to validate competing design alternatives.

Besides the lack of architect-friendly BPS tools, another complicating factor is the communication between the designers, and other actors, such as engineers, and clients. It is important for a client to understand the outcome of such BPS tools and the implications on the architecture of buildings [6], but many clients still do not see the need for paying consultant fees for performing energy simulations [17,18] even though it might save them money in the long run.

## 2. Method

In order to identify the barriers of existing tools and methods, the needs for improved tools, and to gain insight into architects' methods, the IEA-SHC Task 41 performed a survey amongst build-

ing professionals in 14 participating countries, and interviews were conducted with 23 architects in Scandinavia.

### 2.1. Survey

The survey was designed by the international Task 41 expert team and then programmed into Questionform [19], an online survey creator. Then, in each participating country, one national coordinator involved in Task 41 distributed the survey to building professionals in his/her own country. These coordinators used a variety of methods to reach practitioners: by publishing links for surveys through national associations of architects, through professional newsletters and magazines, through custom mailing lists developed from yellow pages or the like. A total of 627 responses were received from 14 countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, Norway, Portugal, South-Korea, Spain, Sweden, and Switzerland). Of these, 350 were considered in the analysis. Many surveys were not analysed because they contained less than 75% of completion. Unfortunately, it was impossible to calculate a precise response rate due to the different distribution methods in every country. Table 1 gives an overview of the amount of respondents reached in the participating countries. In Table 1 can be seen that, in the most pessimistic scenario, a direct response rate of 5.9% was calculated.

### 2.2. Interviews

The survey was chosen as a research method in order to reach a large population of building professionals in many countries. In addition, 23 semi-structured interviews were conducted in Denmark, Norway, and Sweden in order to explore ideas and responses in greater depth, and to be able to study a design process. Similar research carried out earlier within the field of architecture, focussing on the design process, also made use of this method [20–27]. The research method of observations was also considered but found inappropriate since it implied following the design process from the beginning to the end, which would have been a problem since many of the selected buildings were already built. It also required presence of the researcher at many critical times in the process which would be hard to achieve due to the geographical distribution of the projects.

**Table 1**

Amount of respondents reached by direct e-mails or indirectly through links on websites, complete, incomplete questionnaires (missing few questions) and empty questionnaires by participating country.

Country	Indirect contact (i.e. website)	Direct e-mail	Complete	Missing few quest.	Empty	Total	Resp. rate (indirect) %	Resp. rate (direct) %
Australia	est. 9 000	0	78	6	49	133	0.9	n/a
Austria	90	180	17	1	13	31	20.0	10.0
Belgium	n/a	179	16	5	9	30	n/a	11.7
Canada	Eng.		20	9	15	44		
	Fr.		11	3	13	27		
	Total	n/a	1050	31	12	28	n/a	4.1
Denmark	n/a	265	2	0	2	4	n/a	0.8
France	est. 29 000	0	8	0	1	9	0.0	n/a
Germany	n/a	776	8	10	28	46	n/a	2.3
Italy	est. 60 000	100	13	13	34	60	0.0	26.0
Norway	unknown	244	10	12	17	39	n/a	9.0
Portugal	n/a	59	6	0	19	25	n/a	10.2
S. Korea	n/a	286	33	3	34	60	n/a	26.0
Spain	n/a	n/a	7	4	8	19		
Sweden	est. 7 000	1775	27	11	25	63	0.5	2.1
Switzerland	Fr.		1	0	1	2		
	Ger.		7	4	8	19		
	It.		8	0	9	17		
	Total	n/a	920	16	1	27	n/a	1.8
Total		5 834	272	78	277	627	0.5	5.9

**Table 2**  
Interview guide.

Introduction	Design process	Lesson learnt & barriers
<b>Question 1</b> What is solar integrated architecture for you and do you think it is an important aspect of sustainable design?	<b>Question 3</b> Could you describe the early design phase for this project? What was done and what was the role of the participants?	<b>Question 6</b> How did you gain the skills that you presently have with the tools and solar energy in general?
<b>Competences</b> <b>Question 2</b> What basic information and/or knowledge should an architect have before starting designing a project like this?	<b>Question 4</b> Could you describe the rest of the design process in phases?	<b>Question 7</b> What are your lessons learned in this project and how is this project different from other projects done by your office?
	<b>Question 5</b> Which design tools did you use during the design process and how useful did you find these tools?	<b>Question 8</b> According to you, what are the most important barriers for exploiting solar energy as an architect?

Instead, an interview guide was set up to serve as a basis for all interviews with architects (see Table 2). This interview guide was developed with other IEA-SHC Task41 members. The interview guide for urban planners was almost similar, but obviously focused on the urban planning scale rather than the building scale.

### 2.2.1. Procedure

In order to gain a more in-depth insight of architects implementing solar energy into architecture in Scandinavia, several architecture offices were chosen in the countries Denmark, Norway, and Sweden (see Table 3). Additionally, two urban planners were also interviewed in order to highlight barriers in solar integrated urban planning. Many of the selected buildings had also been in the run within subtask C of IEA-SHC Task 41, where case study buildings are gathered with an attractive integration of solar energy.

All selected architects and urban planners were contacted by email and phone and all of them agreed to participate. The architects received the questions prior to the interviews so that they could prepare for it. In general, the interviews lasted between 30 and 60 min, depending on the motivation and availability of the architect. All interviews were tape-recorded. The interviews in Sweden were held in Swedish and translated to English, while all interviews in Denmark and Norway were held in English.

After all interviews were translated and transcribed, data analysis was performed following Glaser and Strauss' grounded theory [28] – a qualitative research method in which theory is derived by systematically gathering data throughout the research process. The provided steps of the grounded theory [29] were followed in order to structure the data and to treat all interviews equally. In order to analyse and code such a large amount of data, the program

QSR NVIVO 7 [30] was used. Within this program, it is easy for the user to import a large pool of sources, code data into categories, search data, and change categories. Categories were set up before the analysis. After coding, the categories were exported to a word processing program.

### 2.2.2. Sample

The 23 interviews were carried out between December 2010 and November 2011 in the cities of Aarhus (DK), Copenhagen (DK), Gothenburg (SE), Karlskrona (SE), Lund (SE), Malmö (SE), Oslo (NO), and Stockholm (SE). The majority of the interviewees (8 female, 15 male) had more than ten years of practical experience. Some of the interviewees were also sustainability coordinators in the office and in one case, the interviewee was an industrial PhD student (a PhD student who is partly employed in an architectural office and partly employed at a university). The interviewed urban planners were also educated as architects. When it comes to the size of the architectural offices and the separate urban planning departments, four of the offices had one to five employees, five had five to ten employees, seven had ten to 50 employees, and seven had more than 50 employees.

## 3. Results

### 3.1. Survey results: respondent's profile

One part of the questionnaire contained a series of personal informative questions. This part revealed that the majority of respondents worked for small or medium sized firms (one to ten employees) mostly active nationally. The respondents' work encompassed a wide variety of projects and building types, with residential buildings being the most common type. Sixty-seven percent (67%) of respondents indicated that they used a 'Conventional project delivery method', with 'Design-Build contracts' and 'Construction Management' being the second most common methods used. The majority of respondents were born between 1960 and 1979. Sixty-six percent (66%) of the respondents were males, and most of the respondents were architects or designers, with a few engineers and other professions also represented. The majority (74%) of respondents had more than ten years of experience.

**Table 3**  
Overview of projects.

Country	Type of project	Completion
Denmark	7 Residential	8 Finished 11
Norway	2 Commercial	5 Not finished 12
Sweden	1 Public	6
	4	
	Urban plan at architecture office	2
	Urban plan at planning department	2

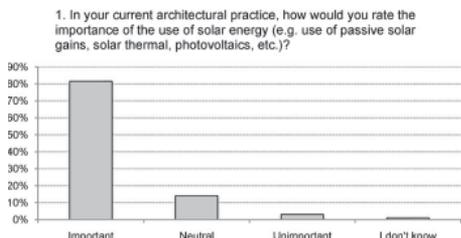


Fig. 1. Distribution of answers for question 1, for all countries (n = 346, four respondents did not answer this question).

### 3.1.1. Interest for solar energy

Eighty-two percent (82%) of the respondents answered that solar energy aspects were important in their current architectural practice (Fig. 1).

The most common solar design strategy used was 'Daylight utilisation', with 74% answering that this was always or often included in their projects. However, the term 'daylight utilisation' was not defined in the questionnaire so it is possible that respondents answered 'yes' based on the fact that they put windows in their building designs and not necessarily used electric light replacement strategies. The second most common strategy was 'Passive solar for heating', with 57% of respondents always or often including this solar design strategy in their projects. Forty-seven percent (47%) always or often included 'Solar thermal for hot water use', while 'Photovoltaics' and 'Solar thermal for heating' were less common (see Fig. 2). The least common solar strategy was 'Solar thermal for cooling', which was used always or often by only 7% of respondents (see Fig. 2).

### 3.1.2. Methods for solar design

The survey questions on methods focussed on the design process as well as the decision making process. The results indicated that respondents used a variety of design processes: (note that respondents were able to select multiple answers) of the 587 answers, there were 192 selections for the fact that 'Integrated design process (IDP)' corresponded best to the architect's own practice, with the remainder divided between 'Intuitive design process' (n = 149), 'Participatory design' (n = 125) and 'Energy-oriented design' (n = 103). Out of the 350 survey participants, sixty-nine percent (69%) of the respondents stated that solar energy

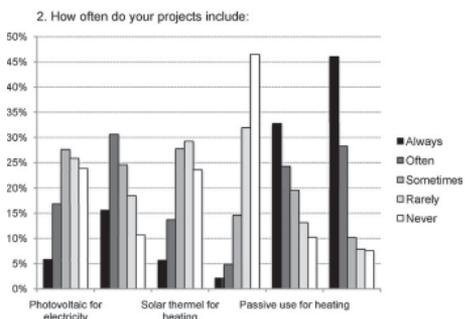


Fig. 2. Distribution of answers for question 2, for all countries (n = 325–342).

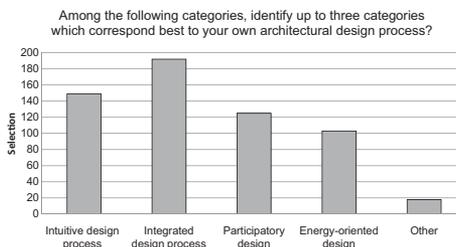


Fig. 3. Distribution of answers for multiple-choice question 16 (n = 587, some respondents selected more than one design process).

technologies were first considered in the conceptual phase, underlining the need for well-developed conceptual design tools. Most respondents answered that they base their design processes upon experiences, interaction with the project owner and by collaborating with others (Figs. 3 and 4).

Responses concerning decision making in small projects indicated that the conceptual phase was largely handled by the architect alone (53%). Specialists were more likely to be involved in later design phases, and multidisciplinary workshops played a fairly small role with a 6–10% response rate depending on design phase. Concerning decision making in large projects, 32% of respondents stated that this phase was handled solely by the architect. External solar energy consultants and building science specialists were relatively common in the later phases of large projects. Multidisciplinary workshops also played a more important role than in smaller projects (10–12% depending on project phase).

### 3.1.3. Tools for solar design

The majority of respondents described their skills with graphical solar design methods as fair (37%) or poor (20%). With regards to solar design tools in CAAD and advanced simulation tools, the majority answered that they considered their skills to be poor (29% and 27% respectively) or very poor (31% and 41% respectively). However, most respondents described their skills with CAAD software, which is an integral part of architects' practice, as advanced (28%) or fair (27%).

A question concerning the software tools corresponding to various design stage were used returned a number of results (Fig. 5a–c). The most commonly used CAAD tools were AutoCAD, Google SketchUp, Revit Architecture, ArchiCAD, Vectorworks and 3dsMax. The most common visualisation tools were Artlantis, V-Ray, RenderWorks and Maxwell Render, while Ecotect, RETScreen,

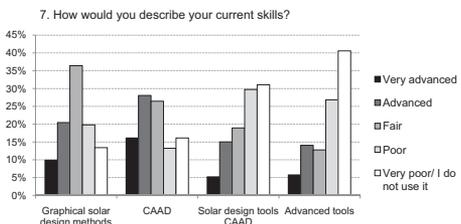


Fig. 4. Distribution of answers for question 7 about the skills with the use of different tools, for all countries (n = 303–310).

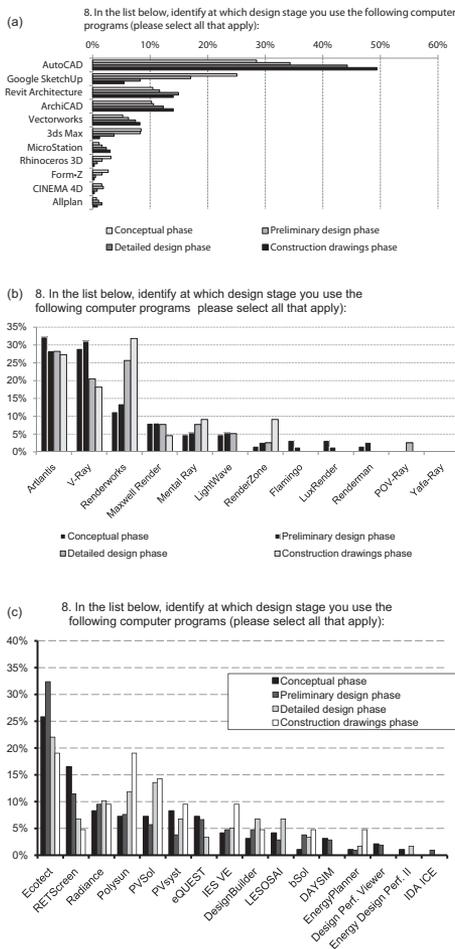


Fig. 5. (a) Distribution of answers for question 8a, for all countries (n=282). (b) Distribution of answers for question 8b, for all countries (n=282). (c) Distribution of answers for question 8c, for all countries (n=282).

Radiance, Polysun, PVSol, PVsyst were the most common tools for simulation.

The most common CAAD, visualization and simulation tools were all used in all project phases, but the distribution of different tools for different phases was specific for each tool. CAAD tools prioritising a simple user interface and rapid modelling (e.g. Google SketchUp) were used extensively in the EDP, while more complex tools (e.g. Revit Architecture, AutoCAD) were more common in the later project phases.

A similar trend is visible concerning simulation software, with some products being preferred in the EDP (e.g. Ecotect, RETScreen)

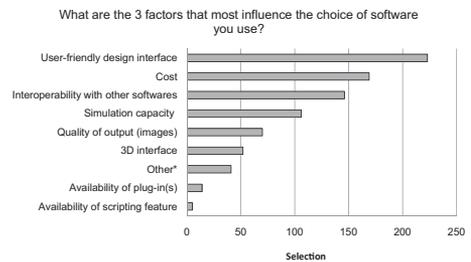


Fig. 6. Distribution of answers for question 9, for all countries (n=826).

and other, more specific and complex tools, used more heavily in later stages (e.g. Polysun, PVSol). The most common visualization software programs were used fairly evenly across the design phases.

The factor that most influenced the respondents' choice of software was a user-friendly interface (n=223). The next most common factors were costs (n=169), interoperability with other software (n=146) and simulation capacity (n=106). Quality of output (images), 3d interfaces, availability of plug-ins and availability of scripting features were considered to be less important (note that respondents were able to select multiple answers). (Fig. 6)

3.1.4. Tools: satisfaction and barriers

Respondents reported various degrees of satisfaction with their chosen software programs (CAAD, visualization and simulation tools) in terms of support for solar building design. For many programs, the response rate was so low that it was impossible to formulate meaningful conclusions.

The most common barriers reported by respondents were 'Tools are too complex' (n=126, see Fig. 7). Other common barriers were 'Tools are too expensive' (n=97), 'Tools are not integrated in CAAD software' (n=80) and 'Tools take too much time' (n=77). Respondents also stated that existing tools are not integrated in normal workflow (n=71), that the tools do not adequately support conceptual design (n=60), and that they are too systemic (n=54). In hindsight, the term 'systemic' might have caused confusion since it can mean either that the program is focussed on one system or that the program looks at the whole range of systems. The answer that existing tools are satisfactory was only selected 13 times (note that respondents were able to select multiple answers).

3.1.5. Improvements needed

Respondents were then asked about the need for improved tools in each design phase. In the conceptual phase, 28% answered they would like to have 'Improved tools for visualization', followed by 'Preliminary sizing' (20%) and 'Tools that provide explicit feedback' (18%). In the preliminary design phase, the most common request was 'Improved tools for preliminary sizing' (26%), followed by 'Tools for key data' and 'Explicit feedback' (22% and 20% respectively). For the detailed design phase, most respondents requested improved 'Tools for key data' (28%), followed by 'Preliminary sizing' (18%), 'Explicit feedback' and 'Visualization' (both 16%). The most common response for the construction drawings phase was 'I don't know/not applicable' (29%). However, 21% also wished 'Improved tools for key data', 16% for 'Preliminary sizing', and 10% for 'Tools that provide explicit feedback'.

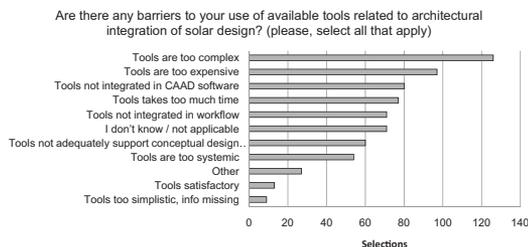


Fig. 7. Distribution of answers for question 11 (n=685).

### 3.2. Interview results

During the interviews, architects were asked first what solar integrated architecture was for them in order to make sure that the terminology was clear for the rest of the interview. Almost all architects mentioned first the active utilisation of solar energy (PV and ST) and later on they mentioned passive utilisation (daylight, heat).

#### 3.2.1. Knowledge and competences

Many architects mentioned that designing solar integrated architecture required more technical knowledge than usual. The majority of them experienced that their current level of technical knowledge was too low and that they needed to develop this. A high level of technical knowledge was found necessary to talk to the engineers and quickly take design decisions.

The need to develop an *extensive* technical knowledge was not felt in every architectural office. It was seen as something unnecessary, since it was considered to be too costly and outside the architecture domain. Instead, architectural offices developed collaborations with engineering firms. Some architecture offices also employed their own engineers. In two Danish architecture offices, industrial PhD students supported the design process and provided project architects with design tools. At the urban planning departments of the cities of Lund and Malmö, collaborations with engineering firms and other consultants were developed to bridge the gap in technical knowledge. When looking at the content of this technical knowledge, architects mentioned mainly the following elements: (1) local climate conditions (temperature, wind, sun paths), (2) active solar systems (how to implement them, needed components and space, dimensions of the needed active systems in relation to the energy need of the building), (3) costs, (4) other technical systems in the building like ventilation, and (5) construction methods.

It was not always perceived as easy to gain the necessary knowledge. Most architects said they had developed their knowledge by taking part in real projects; a method called by the architects as 'learning by doing'. This result is in line with the results of the survey, which also showed that the design processes of architects are mainly based on experiences. Other forms of knowledge acquisition which was mentioned by the architects were 'working with the engineers', 'attending conferences and workshops', 'going on study trips', and 'reading literature'.

#### 3.2.2. The design process

In almost all design processes, a goal was identified at the beginning of the project: a low-energy (solar) building or sustainable urban district. In the buildings designed before 2000 or in the early 2000s, no specific and measurable goal was defined more than that

the building needed to be 'sustainable'. In the later 2000s, goals became more clear and measurable. Using active solar technologies was only in some cases a goal from the beginning; in other design processes, solar technologies were considered from the beginning but abandoned later in the design process since they were found to be too expensive in the clients' view. However, the amount of solar energy contributing to the building's energy balance was never explicitly quantified.

Newer, stricter building regulations in the Scandinavian countries (and the European Union) have forced clients, both private and public, to focus more on energy use and renewable energy sources. In many cases, the clients discovered that getting their buildings certified according to green building labels (LEED, BREEAM, etc.) would increase the value of their property and they were therefore willing to pay extra for this.

#### 3.2.3. Team work

In the projects designed (and built) in the early 2000s, architects started to adapt their usual design process (traditional design process) by consulting engineers in an earlier stage than normally done. In projects designed (and built) later, many architects qualified their design process as an Integrated Design Process (IDP), often in relation to large-scale buildings. It was hard to verify if processes really complied with all the elements of the IDP, but architects mentioned mostly the early engagement of engineers in the process as a clear sign of this. This early collaboration with engineers was found to be crucial for solar integrated architecture, but this collaboration was not always easy: architects experienced that engineers 'spoke another language', were often 'too specialised', and 'not willing to compromise on certain issues'. In some cases, engineers outnumbered the architects in a design meeting, which was felt as uncomfortable for the architect.

#### 3.2.4. Design decisions

The early design phase of the traditional design processes was mostly in the hands of the architects, with a very limited influence of the engineers. After this early design phase, drawings were handed in to the engineers who performed calculations and simulations. In the design processes qualified by the architects as IDP, the process was more iterative and dynamic. In some cases, all actors gathered in a workshop to come up with a first idea and sketch of the building. In other cases, several design alternatives were proposed by the architects and with the help of simulations and calculations performed by the engineer, the best solution was further developed.

In the design process of the urban planners, meetings were organised to discuss solar energy, where researchers and different stakeholders, specialists, were invited to assert the role that solar energy could play in the future. The target group of these

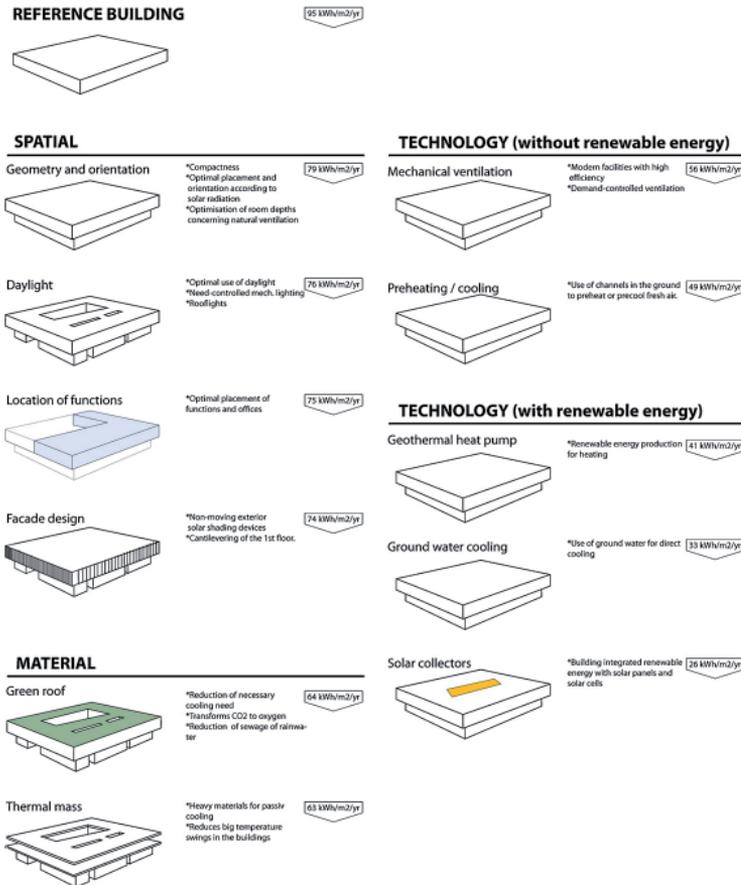


Fig. 8. Consequences of different design parameters on the energy use of a building. An example out of the design process of a Danish architect designing an office building (after Henning Larsen Architects).

meetings was mainly real estate developers. The developed urban plans were regarded by the urban planners as a non-conflicting issue, but a clear and measurable goal for this implementation was never defined. Furthermore, the urban planners acknowledged that they lacked the competence to achieve a solar energy scheme in its full potential.

Communication with the client about solar energy and energy in general was felt as a rather underdeveloped skill amongst the architects, which was due to several factors like a lack of proper tools, and a lack of knowledge. Only some architects were able to give a clear and visual overview of the impact of energy related decisions on the architecture. In Fig. 8, an example can be seen of a roadmap of different design decisions and its impact on the used energy. It was presented to the client to show which steps were necessary in order to reach the desired energy use.

### 3.2.5. Design tools

In the design processes of the projects prior to or in the early 2000s, no advanced BPS tools were used, simply because they could only be handled by experts and at this time these tools did not integrate well into their work flow. In the projects designed later, i.e. between 2000 and 2011, BPS tools were used more often. Interestingly, there was a noticeable difference between the three different countries. In Norway and Sweden, hardly any architect used BPS tools themselves in the discussed projects. Instead, they used simple rules of thumb while they collaborated with engineers who simulated the building's energy performance (only one Swedish architect had used an advanced BPS program). Some of the architects clearly stated that they did not want to gain an extensive knowledge of these programs because it would be too costly. However in Denmark, many architects were using advanced BPS

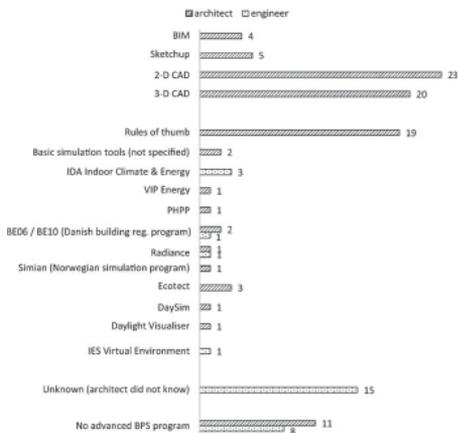


Fig. 9. Tools used in the design process.

programs themselves. Often, architects used these tools as real design tools by comparing different design alternatives relatively (i.e. worse or better performance) rather than absolutely (i.e. a certain energy use of the building). Simulating the absolute energy performance was still in the hands of external engineers who had the legal responsibility for the outcomes. In this way, the Danish architects were able to validate more design alternatives and show the consequences on the architecture, while providing almost instant feedback to the design team instead of waiting for an external engineer to perform a similar simulation.

An overview of the tools used in the design processes is presented in Fig. 9. Interestingly, many architects were not able to name the BPS tools which the engineers used. Architects mentioned to have used simple rules of thumb for solar energy during the design process, which mainly provided input for the dimensions of PVs or Solar Thermal panels, the best inclination and the orientation. Within the urban planning projects, only qualitative studies concerning daylight and shading were performed, mainly with the help of Google SketchUp. In projects achieved in the late 2000s, Building Information Modelling (BIM) was used in the design process and it often concerned large-scale buildings.

#### 4. Conclusions and discussions

This article presented the results of an international survey amongst building professionals in the framework of IEA-SHC task 41-solar Energy and Architecture and interviews conducted with Scandinavian architects with the objective to identify barriers of existing tools and methods for solar design, the needs for improved tools, and to gain an insight into architects' methods of working during the design process. The survey and interviews both strongly indicate the need for further development of software tools for solar architecture, focusing on a user-friendly, visual tool which can generate clear and meaningful results. Also, since each design phase has its own requirements and specifications, design tools should be able to adapt to specific design phases. Future BPS tools should work as a design tool, being able to support comparisons between competing design alternatives in relation to energy use and production in order to support the architects. Respondents answered that there is a need for tools to be easily compatible with the existing work flow of the architect. This can be interpreted

in several ways: either future BPS tools should get a (better) integration into current CAAD programs, or they should be able to stand alone with importing (and exporting) geometry in a satisfying way. One attempt to overcome the problem of import and export is the introduction of the current IFC (Industry Foundation Classes) file format. It is becoming a building standard [31] and attempts to have all software producers to use the same standard which increases interoperability. However, interoperability between the IFC file format and major software packages is still not optimal. Architects and other actors can save costly time when the import and export of geometry between programs will run without errors, something which is currently not the case.

Implementing BPS tools into current CAAD software will require a shift from tool developers' focus from purely CAAD towards a whole performance simulation tool. Developing BPS tools as standalone programs can be done by developers who already have built up an extensive knowledge. However, some technical difficulties might occur in both situations, since many BPS tools were developed before the current CAAD standards got widely accepted in the industry. This might lead in many cases to the need for the total reprogramming of the program.

In the interviews, those architects who used BPS tools, often used more than one program at the same time during the design process to simulate several aspects of the energy performance of a buildings, e.g. daylight conditions, energy production of solar technologies, and thermal balance. Combining all such separate programs into one environment, using the same geometry model, would be preferable and speed up the iterative design process. The recent launch of several BPS tools with such features has made clear that the industry is working towards such programs.

A parallel could be drawn to the role of visualisation programs. During the last decade, these programs helped architects to judge design options but more importantly, it helped them to 'sell' their ideas visually.<sup>1</sup> If BPS tools could be used in the same way throughout the design process, architects would be able to sell energy concepts much better. Communicating with the client is crucial for making design decisions in the design process. If the client is shown what consequences some design decisions have on the energy performance of buildings as well as the financial consequences are provided, a better performing, low-energy solar architecture can be reached.

The survey and interviews also indicated a strong awareness about solar aspects among respondents. However, this was combined with a limited use and knowledge of solar energy technologies, suggesting the need for further skill development amongst architects and tool development to accelerate the implementation of these technologies in future buildings and urban fabric.

The results also showed that traditional, graphic solar design tools or rules of thumb are still in use by many architects since they provide more direct insight, supporting iterative design decision. For instance, the inclination of a roof and its suitability for solar cells can be tested more directly. However, results of the survey showed that only a third of the architects judged their skills of graphic solar tools as fair. That means that the potential of these simple, graphic design tools might be underutilised. If rules of thumbs were more widespread, it could help more architects in the very early design phase. There is also a risk that the more recent architectural education, which has focused on computer literacy, may have failed to properly teach the simpler, graphical, performance tools. Taking solar energy into account has been part of several (architectural) student projects, often implemented in a design studio environment [32–35]. Building performance simulations tools were used

<sup>1</sup> However, it needs to be kept in mind that most of the visualisations are pure cosmetic images often not based on true lighting levels.

in most of the projects in order to give feedback to students on the impact of their design decisions on the energy performance of buildings. Often, the students were taught basics of solar energy in the beginning of the design assignment. The use of BPS tools was integrated in such a way that students got familiar with them. In the case of an experiment set up by Otis [35], two groups were formed; one group used traditional solar design tools, while the other group made use of BPS tools. In the end of the experiment, the test group which used a BPS tool outperformed a group which used traditional solar design tools.

If the shift can be made to better and easier-to-use software tools for building performance simulation, design processes will get more efficient as well as the end product of these process; low-energy (solar) buildings.

### Acknowledgements

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### Appendix A. Online questionnaire

Questions and survey layouts were developed during the IEA-SHC Task 41 meetings and through e-mail exchanges with the collaboration of international experts. The survey consisted of 22 questions and included three question types: multiple choices of specific categories, a single selection of a specific category and open end question (free text). To gather the desired data, the questions were divided into the following categories:

#### A. Solar energy in general:

##### Question 1

In your current architectural practice, how would you rate the importance of the use of solar energy (e.g. use of passive solar gains, solar thermal, photovoltaics, etc.)?

<important, neutral, unimportant, I don't know>

##### Question 2

How often do your projects include: photovoltaic technologies for electricity, solar thermal technologies for domestic hot water, solar thermal technologies for cooling, passive use of solar gains for heating, daylight utilization strategies?

<always, often, sometimes, rarely, never>

#### B. The design methods:

##### Question 3

In which design phase would you first consider the integration of solar energy technologies?

<conceptual phase, preliminary design, detailed design, construction drawings>

##### Question 4

Among the following categories, identify up to three categories which correspond best to your own design process:

<experiences, rules of thumb, design guidelines, computer simulations, expert systems architecture, interactions with the owner, interactions with future users, several propositions, collaboration with others>

##### Question 5

How would you handle decision making for the integration of solar energy technologies in your project in the case of smaller, less complex projects?

<do it myself; consult a colleague architect; involve an internal solar energy consultant; involve an external solar energy consultant; involve a building science specialist; arrange multidisciplinary workshops; involve other profession>

##### Question 6

How would you handle decision making for the integration of solar energy technologies in your project in the case of larger, more complex projects?

<do it myself; consult a colleague architect; involve an internal solar energy consultant; involve an external solar energy consultant; involve a building science specialist; arrange multidisciplinary workshops; involve other profession>

#### C. Tools for solar design:

##### Question 7

How would you describe your current skills regarding: graphic solar design methods, CAAD, solar design tools in CAAD, and advanced tools)?

<very advanced, advanced, fair, poor, very poor>

##### Question 8

In the list below, identify at which design stage you use the following computer programs

(8a: CAAD tools: Vectorworks, Rhinoceros 3D, Microstation, Lightworks, Houdini, Form-Z, Digital project, Cinema 4D, Caddie, Blender, ArchiCad, 3DS Max)

(8b: Visualization tools: Yafaray, V-Ray, RenderZone, Renderworks, Renderman, POV-ray, Mental Ray, Maxwell Render, LuxRender, LightWave, Flamingo, Artlantis)

(8c: Simulation tools: RETScreen, Radiance, PVSyst, PV\*SOL, Polysun, LESOSAI, IES VE, IDA ICE, eQUEST, Energy Design Performance, Ecotect, Design Performance Viewer, DesignBuilder, Daysim, bSol, BKI Energieplanner)

<conceptual phase, preliminary design, detailed design, construction drawings>

##### Question 9

What are the 3 factors that most influence the choice of software you use?

<user-friendly design interface, cost, simulation capacity, interoperability with other software, availability of scripting feature, availability of plug-in(s), quality of output (images), 3d interface, other>

##### Question 10

For the programs you currently use, express how satisfied you are with their support for solar building design:

(10a: CAAD programs: Vectorworks, Rhinoceros 3D, Microstation, Lightworks, Houdini, Form-Z, Digital project, Cinema 4D, Caddie, Blender, ArchiCad, 3DS Max)

(10b: Visualization tools: Yafaray, V-Ray, RenderZone, Renderworks, Renderman, POV-ray, Mental Ray, Maxwell Render, LuxRender, LightWave, Flamingo, Artlantis)

(10c: Simulation tools: RETScreen, Radiance, PVSyst, PV\*SOL, Polysun, LESOSAI, IES VE, IDA ICE, eQUEST, Energy Design Performance, Ecotect, Design Performance Viewer, DesignBuilder, Daysim, bSol, BKI Energieplanner)

<very satisfied, satisfied, neutral, dissatisfied, very dissatisfied>

##### Question 11

Are there any barriers to your use of available tools related to architectural integration of solar design?

<The tools are not adequately supporting the conceptual design stage; The tools are too expensive; The tools are too complex (high learning curve); Using the tools takes too much time; The tools are too systemic (do not support integration of active/passive/daylight design); The tools are not integrated in our normal workflow; The tools are not integrated in our CAAD software; The tools are too simplistic and do not give me the information I require; No, I

find available tools quite satisfactory; I don't know/not applicable; Other>

**Question 12**

Do you see a need for improved tools to support the integration of solar building design?

<Yes, we need improved tools for visualization (architectural integration); Yes, we need improved tools for preliminary sizing of solar energy systems; Yes, we need improved tools for providing key data (numbers) about solar energy; Yes, we need tools that provide explicit feedback (key data) in connection with building massing and orientation; No, I find available tools quite satisfactory; I don't know/not applicable; Other>

**Question 13**

Please specify other needs regarding tools or methods: (open question)

The questionnaire ended with general inquiries concerning the type of architectural office the respondents worked in and personal informant questions.

Informative factual questions (for statistical purposes only)

**Question 14**

Number of employees in your firm:

<Less than 3; 3 to 10; 11 to 50; More than 50>

**Question 15**

Among the following building categories, which one(s) correspond(s) the most to your architectural practice?

<Building renovation; New buildings; Residential buildings; Commercial buildings: retail stores, shopping centers, etc.; Commercial buildings: office buildings, Educational buildings: schools, kindergartens, etc.; Institutional buildings: hospitals, health care facilities; Institutional buildings: museums, exhibition centers, libraries, etc.; Government buildings; Industry/factory/storage buildings; Other>

**Question 16**

Among the following categories, identify up to three categories which correspond best to your own architectural design process?

<Intuitive design process (i.e. instinctive decisions made without conscious thought. It often refers to the architect's experience.); Integrated design process –IDP (collaboration with others professionals in multidisciplinary teams); Participatory design (interaction between the future users of the

building, e.g. public participation); Energy-oriented design (i.e. practicing sustainability with calculator and computer simulation); Other>

**Question 17**

Among the following categories, identify the category which corresponds best to your own architectural practice?

<Traditional (conventional) practice with variety of projects; Traditional (conventional) practice with focus on building renovation or restoration; Design-Build (DB); Construction management (CM); Other>

**Question 18**

Is your firm active...

<Nationally; Internationally; Both nationally and internationally>

Personal factual questions (for statistical purposes only)

**Question 19**

When were you born?

(open question)

**Question 20**

Gender:

<male, female>

**Question 21**

Profession:

<Architect/Designer, Engineer, Physicist, Other>

**Question 22**

Professional experience:

<Less than 5 years; 5 to 10 years; more than 10 years>

The questionnaire ended with an open question ('Please add here any comment you wish to add to this survey').

**Interview guide for architects**

Introduction	Design process	Lesson learnt & barriers
<p><b>Question 1</b></p> <p>What is solar integrated architecture for you and do you think it is an important aspect of sustainable design?</p>	<p><b>Question 3</b></p> <p>Could you describe the early design phase for this project? What was done and what was the role of the participants?</p>	<p><b>Question 6</b></p> <p>How did you gain the skills that you presently have with the tools and solar energy in general?</p>
<p><b>Competences</b></p> <p><b>Question 2</b></p> <p>What basic information and/or knowledge should an architect have before starting designing a project like this?</p>	<p><b>Question 4</b></p> <p>Could you describe the rest of the design process in phases?</p> <p><b>Question 5</b></p> <p>Which design tools did you use during the design process and how useful did you find these tools?</p>	<p><b>Question 7</b></p> <p>What are your lessons learned in this project and how is this project different from other projects done by your office?</p> <p><b>Question 8</b></p> <p>According to you, what are the most important barriers for exploiting solar energy as an architect?</p>

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# Article V



## Architects' design process in solar-integrated architecture in Sweden

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Architects can play a key role in future solar-integrated architecture as they are involved in the building process from the beginning. Solar-integrated architecture takes both passive and active use of solar energy into account. The aim of this research was to gain insight into the actual design processes of solar-integrated buildings. Therefore, semi-structured interviews were conducted with Swedish architects who designed such buildings. Results showed that teamwork was experienced as crucial and building performance simulation tools were hardly used by the architects themselves. Results from these interviews serve as input for the development of new architectural guidelines for designing solar-integrated architecture as part of IEA-SHC Task 41: Solar Energy & Architecture.

**Keywords:** Design process; architectural design; solar energy; teamwork; design tools

### Introduction

In the last decade, sustainable architecture has grown from a niche market to a more mainstream movement. In Europe, the Energy Performance of Buildings Directive (EPDB 2010) requires all new buildings to be nearly zero-energy buildings by 2020. In order to achieve such buildings, they not only need to be energy efficient, but also need to generate energy; obviously, this implies that solar energy can play an important role. By rationally taking into account the characteristics of solar radiation in both a passive and an active way, a solar-integrated architecture can be achieved.

The aim of this research was to gain insight into the design process used in architectural offices for solar-integrated projects in Sweden. Therefore, a series of 11 interviews was performed among Swedish architects. It was important to see which actors were involved, what kind of information those actors shared, what kind of knowledge they needed, what design tools they used etc.

Architects can contribute significantly to a more energy-efficient built environment as they make key decisions early in the design process (Wall *et al.* 2009). It is, however, unclear as to how architects make design decisions concerning energy and on what grounds these decisions are made. Research performed earlier has shown how architects have dealt with designing solar-integrated architecture in Canada, Denmark, Singapore and the USA (Charron 2008, Brunsgaard 2011, Kosoric *et al.* 2011, Otis 2011). The role that design tools played was new and crucial. In the design process of Danish low-energy houses, two methodical approaches of building performance simulation (BPS) tools' use existed; a case-based approach

and parametric approach (Hansen and Knudstrup 2008). With the parametric approach, engineers can take a proactive role in the design process. Other Danish research showed that the collaboration of different actors, an interest in each other's disciplines and a common goal were beneficial for the design process (Brunsgaard 2011).

In the case of Canadian low-energy houses, Genetic Algorithm software was shown to be highly efficient in solving complex problems in the design process and therefore an important support for the architect (Charron 2008). In the design process of a building with integrated photovoltaics in Singapore, different design alternatives were developed and with the help of a multi-criteria decision-making tool, the best alternative regarding energy performance, economic performance and functional-aesthetic criteria was selected (Kosoric *et al.* 2011). At the Harvard Graduate School of Design, a study was carried out to evaluate how solar design tools may affect the development of form in the design process (Otis 2011). It was shown that students who used solar design tools outperformed those students who did not use any design tool.

BPS tools and other design tools can provide feedback to architects and help them make decisions in the design process. Research performed earlier within IEA-SHC Task 41: Solar Energy & Architecture has shown that many architects still see a need to improve tools and methods for architects (Kanters 2011a). Other researchers arrived at a similar conclusion; BPS tools are not yet suitable for architectural design work, are found to be too complex and not compatible with the architect's working methods (Attia *et al.* 2009), and have serious shortcomings when

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net-zero-energy buildings have to be designed efficiently (Biesbroek *et al.* 2010). Recently, however, new design tools have been launched which connect the architect's CAD environment with solar analysis tools, to name a few: IES VE for Google SketchUp and REVIT (IES 2010), Ecotect (Autodesk 2011a) and Vasari (Autodesk 2011b) and DIVA for Rhino (GSDSquare 2009). With the introduction of these programmes at least one parameter – embedding into the architect's work flow – might be solved, but still a lot of parameters remain unsolved (for instance, a good interoperability between the programmes).

It is known that passive application (solar heating and daylighting) and active application (photovoltaic and solar thermal systems) of solar energy both imply significant architectural consequences (orientation, geometry, fenestration, HVAC system, etc.). Active solar elements can become part of the architecture of a project when the architect applies a holistic approach (Hestnes 1999), and when these solar elements replace other building elements (Lundgren and Torstensson 2004). The passive application, with the current focus on passive houses – a house which requires a highly insulated climate shell, a high-efficiency heat exchanger in the ventilation system (Janson 2010) and appropriate orientation – shows that a positive development within the building industry is possible.

The new emphasis on energy efficiency starts to change the building process from the so-called traditional building process to newer forms. The traditional design process was divided into the following phases according to Jones (1992): (1) briefing, (2) pre-conceptual design, (3) conceptual design, (4) preliminary design, (5) detailed design and (6) design documentation. Newer forms, like the integrated design process (IDP), are built upon teamwork, all actors are involved from the early design phases and has the following sequence (AIA 2007): (1) conceptualization (programming), (2) criteria design (schematic design), (3) detailed design (design development) and (4) implementation documents (construction documents). Within IEA-SHC Task 23: *optimization of solar energy use in large buildings*, the subject of IDP was dealt with in a more extensive explanatory way and several projects were showcased to give concrete examples of IDPs (IEA 2003). The case studies selected in this research were supposed to use a design process that could be qualified as an IDP rather than a traditional process. It was also expected that architects who already designed solar-integrated architecture and urban master plans could serve as an example for other architects willing to design solar-integrated architecture. Furthermore, it was expected that the selected architects could indicate where the possibilities and problems had been and would be able to compare it with design processes and conditions of 'regular' buildings.

The conducted interviews contribute to the research carried out within subtask B of IEA-SHC Task 41: Solar Energy & Architecture. This task gathers researchers and architects from 14 countries with the aim to accelerate

the development of high-quality solar architecture. Subtask B focuses on tools and methods that architects use when designing solar architecture. Previous publications of subtask B consist of an overview of BPS tools (Dubois and Horvat 2010) and an international survey on the adequacy of design tools (Horvat *et al.* 2011).

## Methods

The semi-structured interview was selected as the main research instrument since the focus of the investigation was on the process. Semi-structured interviews also give a certain degree of freedom to express ideas and to highlight areas of particular interest and expertise. It also makes it possible to explore some responses in greater depth (Horton *et al.* 2004). The interviews can be seen as a supplement to the IEA-SHC Task 41's international survey which was mentioned earlier.

## Procedure

After the decision was taken to use semi-structured interview, a selection of architectural offices was made. The architects who were selected for the interviews had been participating in projects with a focus on solar utilization. Furthermore, several buildings were part of a selection of case study buildings gathered within the IEA-SHC Task 41 during task meetings. In Table 1, an overview is presented of the selected projects. Although it was intended to focus mostly on built examples of solar-integrated buildings/urban master plans, not all the case studies were actually finished at the time of the interview.

The selected architects were contacted by email and phone and all approached architects participated. Within the architectural offices, these architects who had been project leaders were selected as interviewees. The interview questions were sent to the interviewees prior to the interviews to allow the architects to prepare themselves for the interview. The interviews usually lasted from half-an-hour to more than an hour, depending on the architect and the available time. Interviews were held in Swedish and tape-recorded. After the interviews had been conducted, they were directly transcribed in Swedish and later entirely translated into English. The interview questionnaire (Table 2) was developed during IEA-SHC Task 41 work meetings with other Task members and was set up in order to serve as a basic guide to all interviews, although architects were free to express other thoughts or reflexions on solar-integrated architecture. One pilot interview was conducted which allowed refining the questions. Answers given in the pilot interview were, however, considered not to be different from other interviews and were therefore fully taken into consideration in the final analysis.

Data analysis of the interviews was carried out using Glaser and Straus' grounded theory (Glaser and Strauss 1967), which has been used earlier in analysis of the

Table 1. Overview of projects.

Architect	Office location	Project location	Latitude	Type of project	Built
1	Stockholm	Kolding, Denmark	55.7N, 11.9E	Residential	Yes
2	Stockholm	Trosa, Sweden	58.9N, 17.5E	Residential	Yes
3	Stockholm	Stockholm, Sweden	59.3N, 18.1E	Urban plan	Yes
4	Stockholm	Stockholm, Sweden	59.3N, 18.1E	Commercial	No
5	Gothenburg	Stockholm, Sweden	59.3N, 18.1E	Residential	Yes
6	Gothenburg	Gothenburg, Sweden	57.7N, 11.9E	Urban plan	No
7	Gothenburg	Gothenburg, Sweden	57.7N, 11.9E	Commercial/public	Yes
8	Gothenburg	Visby, Sweden	57.6N, 18.3E	Public	Yes
9	Malmö	Malmö, Sweden	55.6N, 13.0E	Residential	Yes
10	Malmö	Stångby, Sweden	55.7N, 13.2E	Residential	No
11	Malmö	Malmö, Sweden	55.6N, 13.0E	Residential	No

Table 2. Interview guide.

Introduction	Competences	Design process	Lesson learnt and barriers
<i>Question 1</i> What is sustainable architecture for you and how important is it for you? What is solar-integrated architecture for you and do you think it is an important aspect of sustainable design?	<i>Question 2</i> What basic information and/or knowledge should an architect have before starting designing a project like this?	<i>Question 3</i> Could you describe the early design phase for this project? What was done and what was the role of the participants? <i>Question 4</i> Could you describe the rest of the design process in phases? <i>Question 5</i> Which design tools did you use during the design process and how useful did you find these tools?	<i>Question 6</i> How did you gain the skills that you presently have with the tools and solar energy in general? <i>Question 7</i> What are your lessons learned in this project and how is this project different from other projects done by your office? <i>Question 8</i> According to you, what are the most important barriers for exploiting solar energy as an architect?

(architectural) design processes (Wong 2010). Within the grounded theory the following steps are performed after data collection (Bryman 2008): 'coding' (the process of categorizing data), 'constant comparison', 'saturate categories', 'explore relationships between categories' and 'conceptual and theoretical work'. By using an interview guide, a list of categories could be made prior to the coding in order to make the process of coding easier. Furthermore, transcriptions were read several times before coding, as well as notes taken during the interview. Then, transcriptions of the interviews were imported into the programme QSR NVivo 7 (QSR-International 2006). This data analysis programme allows users to process raw data into categories, and is especially helpful when large amounts of data need to be analysed. The coding in NVivo is done by selecting a part of the transcriptions and dragging it into the selected list of categories. Within the programme, the categories were saturated with all data from all interviews and all categories were exported to a word-processing software.

After the interviews, the architects were asked to provide some data from the design tools used in the processes, as most of the interviewed architects answered to have used design tools and BPS tools in some way or the other. In this

way, it would be possible to see at what level architects make use of tools. However, only three architects responded to the request and there was a large variation in the quality of the sent documents.

### Sample

Eleven interviews were conducted from January 2011 to May 2011. All interviews were at the architectural offices of the architects, which were located in Stockholm, Gothenburg and Malmö in Sweden. Additional interviews were carried out in Norway and Denmark, but these will be discussed in a future publication.

Most of the interviewed architects – of which four women and seven men – had more than 10 years of experience as architect. In almost all case studies, the project architect was leading a small team of other architects and, if applicable, was responsible for contact with external consultants. The architectural offices were also carefully selected in order to ensure a rather equal distribution of sizes as it was expected that offices of different sizes would use different design methods, which is related to the means in terms of organization and available in-house skills. In the

sample, two offices had 1–5 employees, three offices had 5–10 employees, two offices had 10–50 employees and four offices had more than 50 employees.

**Results**

*The architect's view on solar-integrated architecture*

When asked about their definition of sustainable architecture, all architects came up with their own definition. However, most of them agreed that sustainable architecture has a minimal impact on its environment in the long term. In Figure 1, an overview is presented of the themes mentioned by the interviewed architects when asked about the term sustainability (note that the architects were allowed to give more than one answer).

The architects defined solar-integrated architecture as an important part of the whole sustainability field. The term 'integrated' meant for architects that it was part of the architecture and the aesthetics of the whole building. In some cases, integrated was conceived as solar energy products replacing other building components and materials, not as an add-on afterwards.

When talking about solar-integrated architecture, most architects mentioned first the active application of solar-integrated architecture – solar panels and solar cells – and secondly the passive application of solar-integrated architecture – passive heating and daylighting. Furthermore, architects seemed to be aware of the relationship between solar radiation and energy use in buildings; windows were seen not only as a way of confronting the inner environment of a building with its outer environment, but also as devices letting in daylight and heat. The risk of overheating in the summer was considered to be taken into account by providing proper solar shading – while still providing sufficient levels of daylight; a situation which could lead to a conflict. Some architects used this conflict as a

driving force in the design of the building by both blocking abundant solar radiation and producing electricity by solar cells at the same time.

When it came to solar-integrated urban planning, architects experienced solar energy as only one of many parameters to consider. One architect conceived orientation in urban planning based on passive solar principles in conflict with the dense city. Another architect thought that making more use of solar energy in cities could avoid turning agricultural land into solar energy plants.

*Technical competences of architects*

The architects were asked what competences they should have for designing solar-integrated architecture. Some architects mentioned that architects are generalists and that they should know a little about a lot of aspects of the building, including technical systems. Many architects saw the architect as someone who can do much more than only aesthetically designing a building but he/she needs to have more technical and engineering knowledge in order to be able to design solar-integrated architecture. With this increased technical knowledge, architects should be able to quickly assess design situations. This need for increased (technical) knowledge was often felt as a relatively new demand by the interviewees. However, some of the architects experienced that the architect should not get too much technical knowledge, as it could limit creativity during the design process. In contrast, one architect mentioned that many recent 'sustainable' projects were very superficial; this architect felt more confident with a more fact-based architecture than a sense-based architecture when it comes to sustainability.

Some architects expressed the view that they did not have sufficient knowledge or have the wrong type of technical knowledge and therefore worked together with engineers. One architect also mentioned that gaining and

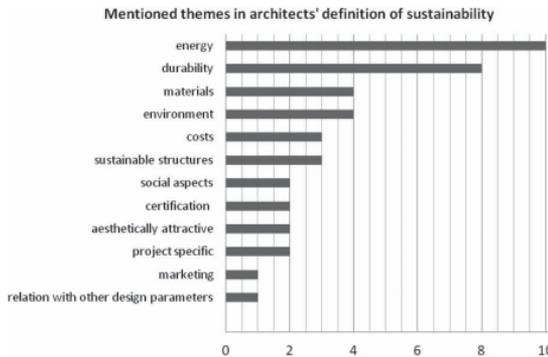


Figure 1. Architects' definition of sustainability.

maintaining an extensive technical knowledge puts a high demand on a small-scale architectural office. Other architects expressed that they did not see the need to have an extended technical knowledge and that they are therefore teamed up with engineers. For many architects, such a close collaboration with engineers – mainly building service engineers – is relatively new and came into the picture after the introduction of stricter Swedish building regulations (building regulations in Sweden included already in 1993 rules about energy issues like heat and transmission losses and since the last decade, they also included demands on the maximum energy use of a building expressed in terms of kWh/m<sup>2</sup>, year). The collaboration between architects and engineers does not, however, always go that smoothly; architects and engineers tend to speak different languages and use different kinds of input in order to perform their job.

The engineer was pretty categorical and technical and (...) 'engineering'. You could get mad at him as an architect. He didn't think like an architect. (architect #7)

[during a conversation between the architect and the engineer about solar cells, the engineer says] 'it has to be this angle and in this direction', but then we as architects sketch and say: 'we want this angle and this direction because it looks better'. Then the engineers perform calculations and then they see that there was not much of a difference. That is the dialogue you want to have (architect #5)

#### **Convincing the client**

Another competence an architect should have is the skill to convince clients to go for solar-integrated architecture. This means that architects had to be able to clearly present the advantages and disadvantages of the integration of solar energy, both regarding the active and passive approach. This was often done by providing a financial overview with the benefits of using less energy vs investment costs. Some architects tried to highlight the symbolic value of solar-integrated architecture for the client.

One architect saw it as her duty as an architect to protect the tenants' interests, which the architect experienced as being endangered by the amount of technology applied in new buildings. Tenants might feel limited in their possibilities to affect their work environment and this architect therefore tried to include the possibility to have a partly manual override for the technical systems in the project.

#### **Basic knowledge**

When asked about the necessary basic knowledge regarding solar-integrated architecture, most architects found it difficult to answer that question. Architects' answers were mainly focused on the technical side of that knowledge. Architects often answered that there is a need for having an overview of available solar technologies and other technical systems. With this overview, an architect should be able to compare different systems with each other based on

their conditions and requirements. The following system requirements were mentioned by the architects:

- angles in which solar systems can have maximum efficiency, which direction suits the situation best;
- how much solar systems could contribute to the energy use of the building;
- need and dimensions of storage tanks.

Other architects mentioned that with this standard technical knowledge, the dialogue with the building service engineers could become easier and it will also give the architect the possibility to propose and adapt systems in order to integrate them in a more aesthetical way. Furthermore, architects expressed a need to have an extensive knowledge about the impact of the physical environment on the building:

- impact of the sun's capacity to heat, but also to overheat a building;
- local wind conditions;
- airtightness;
- how internal loads affect the thermal balance of a building;
- knowledge about window properties and position.

#### **Further education**

As it was found necessary to have more knowledge about solar-integrated architecture as an architect, gaining this new knowledge was found to be difficult by several architects but many of them had a personal interest in the subject. On the urban scale, general as well as technical knowledge was considered to be more elusive for architects to gain, as it is not their direct field of education. Architects experienced that institutions, municipalities and companies could help architects gain more knowledge on this urban level.

Gaining an overview of available solar technologies in buildings and remaining updated was found difficult, mainly due to rapid changes and the development of new products.

You have to update yourself all the time basically. You become very dependent on technology and the technology changes all the time (architect #11)

Many of the architects answered that they mainly gained knowledge by taking part in real projects. Some architects did not have any experience in solar-integrated architecture before starting the discussed project but by going through projects with a focus on solar integration, architects were confronted with the problems and possibilities of the integration of solar energy into buildings.

Another way of gaining knowledge was through collaboration with engineers. Building service engineers were often involved during the design process and architects gained a lot of knowledge by collaborating with engineers. The method of transferring knowledge between architect

and the (building service) engineer differed in each case. In one case, the architect described a working situation where the building service engineer and the architect sat down and sketched together. In another case, the project architect had meetings and email correspondence with the engineer. On the urban scale, transfer of knowledge to architects often occurred through collaboration with larger groups of engineers gathered in municipal departments or other state institutions.

Study trips were considered as an important means of gaining knowledge by architects. They saw it as a source of inspiration directly showing how they could integrate solar energy into architecture. By seeing different examples of integration, architects can make a judgement for themselves of several systems and applications, which could be vital information when designing new buildings. The possibility of visiting good examples can also be an inspiration source for other actors in projects, mainly clients.

That's why it is good and important to have good examples; to visit, to see, to experience it yourself, to have evidence: it is done. This works and it looks damn good. As an architect, I also think that it is very important to show non-architects that kind of examples (architect #4)

Architects also gained knowledge from the literature. Besides books on solar energy, architects saw building regulations and additional building standards as literature, which they need to know extensively. Furthermore, when clients decided to have their buildings certified with additional building standards – like LEED, BREEAM, Building Programme South (a standard developed in Southern Sweden) or Green Building – architects need to be aware of these extra sets of rules. They are often supported by the building service engineers in order to see whether they comply with the rules.

The majority of architects did not attend any course in the field of solar energy. However, some architects did take short-term courses, or invited speakers, mostly other engineers or architects. One architect complained about the lack of possibilities of good further education; according to this architect, nothing had changed that much in the available knowledge on solar technology in the last 20 years.

### *Education as an architect*

Concerning the role of architectural education in relation to sustainable architecture, architects answered differently and found it hard to judge. Some architects stated it was reasonable that the basic architectural education focused on fundamental elements of architecture and aesthetics, because it is hard to learn them afterwards. Working in the industry was often seen as the start of the second education as an architect, when one learns by taking part in projects. Some architects experienced that it is easier to gain technical knowledge afterwards than to gain the aesthetic fundamentals of architecture.

There are a lot of people you can just call and ask [regarding solar energy products]; 'How big is the tank? How much insulation do we need?' There is no one you can call and ask 'is it nice or ugly with this roof angle?' You have to learn that in school (architect #2)

Other architects mentioned the lack of technical focus within architectural education. According to one architect, newly graduated architecture students are designers, not architects, because they do not learn technical aspects of buildings.

### **The design process**

#### *Early consideration*

When comparing 11 projects with their own specifications, conditions, actors and (design) processes, it becomes clear that the emphasis on energy efficiency and the integration of solar energy has been in focus from the early design phase. In almost all cases, it was the client who assigned the architect to design an energy-efficient building. Some of the case studies show that clients were focusing on sustainability/energy efficiency already in the beginning of the 2000s. Because of the current development and attention towards this topic, case studies from the late 2000s and the beginning of the 2010s showed that they also had this emphasis, which is mainly a result of stricter building regulations (in Sweden) and because of the introduction of energy classification systems as a marketing instrument. In some cases, it was not the client, but the architect, who had a focus on sustainability in the early design phase.

Cases studies showed that Swedish municipalities have a special role to play in the design process. In some cases, the municipality was the client (both on building and urban level) and had high ambitions regarding sustainability. When the municipality was not the client of a project, they could still ensure a high sustainability level through the instrument of competitions. When municipalities develop new urban districts, the land is often property of the municipality. Potential property developers are invited to join the competition to be able to buy a piece of land and develop it into properties. This is, however, only possible if the proposed buildings comply with stricter rules as set by the municipality on top of the regular building rules. In this way, municipalities have the possibility to demand these stricter building standards, which would not be possible in the standard procedures.

The architects experienced that throughout the year, clients have become increasingly interested in the positive effect of sustainable architecture. Although the Swedish national building regulations became stricter, clients started to demand certified sustainable buildings that could be according to either BREEAM, LEED, Green Building Standard, Passive House Certificate or Building Programme South (a Swedish programme). When clients are demanding such higher standards, they often want to show that the building is sustainable, which for instance can be done

by clearly displaying solar cells and panels, even though these solar elements were not always located in the most energy-efficient place.

### Teamwork

In order to fulfil the task of designing a sustainable building, architects often team up with engineers to investigate a sustainable strategy for the project from the early design phase. The involved engineers are mostly building service engineers, structural engineers and energy consultants. In the early design phase, the architect and engineer often decided what technical systems were most suitable for the building (based on energy sources available in the surroundings), and how the lowest possible heating and cooling load for the building could be achieved. These components of the project required a lot of knowledge and it was for this reason that the collaboration between engineers and architects was found so important. In smaller, mono-functional buildings, the architect can have this knowledge about technical systems himself/herself. In bigger, multifunctional buildings, the architect can hardly have this advanced knowledge as the technical systems can exhibit a high level of complexity. Architects also did not see the need to have all this extensive knowledge, because it is too technical and difficult to stay updated.

The development of the architectural shape of projects went often hand-in-hand with the applied technical systems; when a certain change in the project was made because of aesthetics reasons (for instance a change in geometry or facade), engineers calculated or estimated the consequences of this on the energy performance of the building and reported it back to the architect.

Then we ended up in the hands of the building service engineer who said 'never in all my life. Check out the new building regulations, we are never going to pass the energy requirements'. The building service engineer said we should start tightening the building; we should have a window composition instead of having [everything in glass] (architect #7)

In this iterative way, the architect could, together with the engineer, decide on what design options were best. It also worked the other way around; engineers proposed a technical system that had consequences for the design of the project. In many cases, this led to compromises; the architecture of the building could not always be as wanted by the architect and the technical systems could not always be how the engineer wanted it. However, this collaboration was often perceived as positive by the architects.

We [the architect and the building service engineer] sat down and sketched together. I think that this is usually the fastest way to [do:] that a person says something about a system that fits together [with the project]. And if it is like this, then you start to discover which consequences it has for the building. If it had [non-desirable] consequences, then you ask ... is there another system that we can have as well?

But we also proposed solutions the engineers didn't think of. (architect #8)

### Solar integration

In the majority of cases, active solar technologies were integrated in the building in the form of solar panels or solar cells. The visibility of the solar panels and cells had a large impact on the architecture; in some cases this was desirable, and in other cases this was not desirable. Displaying the active harvesting of solar energy as an active architectural element is a way of marketing the building and could therefore be wanted by clients and architects. When solar technology was to be displayed in the project, the architect often put some effort in trying to get the solar technology as aesthetically pleasing as possible, for instance, by designing special details.

In some cases, the architect considered that current solar products were not aesthetically pleasing and, therefore, they were not displayed in an obvious, visible way. Even though active solar technologies were proposed in the early design phase of most of the projects, they sometimes did not survive the design process, which was often due to financial considerations by the client. In some cases, solar energy was not applied due to local conditions, which were often related to the local sources of energy (for instance, cheap heat from a district heating network) and made the feasibility of solar technologies less attractive compared with other renewable energy sources. In general, there was a strong belief among architects that they themselves were not the biggest barrier for solar-integrated architecture, but that other factors beyond their power decided whether active solar technology was used or not.

### Design tools

On the question concerning the type of design tools used in the design process, some architects answered that they did not use any. One architect explained that the expression *design tool* is not a familiar expression for what architects use, at least, in Sweden. When design tools are considered as tools or aids when designing, architects used mostly the traditional design tools, that is, hand sketches, two-dimensional and three-dimensional drawings in a CAAD programme as well as physical models. In order to maximize the potential of sustainable architecture and/or solar-integrated architecture, basic information about the energy performance and production in the building could be a useful design aid for architects. This could be achieved in two ways: manually using rules of thumb or by computer with simulation programmes. More recent developments within the software industry have provided more available simulation programmes, but in the case studies from the beginning of the 2000s, only one architect simulated the building using a computerized simulation tool. The interviewed architects were asked to name all BPS tools used in the design process, both used by themselves and by the

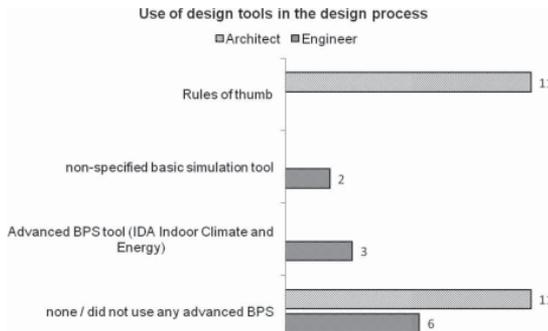


Figure 2. Design tools used in the design process.

involved engineers. If these programmes were used at all, the architects most often ignored what BPS tools were used by the engineers. All architects answered to have mostly used rules of thumb as a design tools, but no architect used advanced BPS tools themselves; if it was used, then it was often the engineer who used these programmes (Figure 2).

Building information modelling (BIM) was not used in any of the case study buildings, even though Swedish results from an international survey showed that BIM software is commonly used nowadays in Sweden (Kanters 2011b). The absence of BIM can be due to the fact that it is quite a recent development in the building industry, and many case studies in this research were older than BIM. Furthermore, BIM is often used in large-scale buildings, whereas many case study buildings in this research were small scale.

All architects mentioned that they used (simple) rules of thumb when designing sustainable/solar-integrated architecture. These rules of thumb often provided a first estimation on

- window area;
- thickness of outer walls;
- dimensions, energy output and most appropriate inclination of solar panels/cells on the building.

Very few architects used BPS programmes by themselves. Sometimes, simple simulation programmes were used by the architects, but more advanced simulation tools were operated by the (building service) engineers. Some architects expressed that using advanced simulation programmes as an architect would imply a big investment as these tools are expensive and future users need to gain knowledge on how to use the programmes.

Besides required investments, some architects doubted that it should be the architect's responsibility to perform advanced simulations; engineers are considered to have more technical knowledge, which is needed for input in the simulation programmes. In line with that two architects

also mentioned the issue of responsibility when it comes to the simulated energy performance of a building.

It's also a bit difficult ... not knowledge-wise, but it is difficult concerning responsibility. You can think of simulation tools as design tools, but you should know whether the outcome is right (or not) (architect #11)

Architects also used other forms of design aids. Some architects mentioned that they saw the national building regulations and additional (stricter) building regulations as a design aid.

### Conditions and barriers of solar-integrated architecture

#### Incentives

Almost a third of the architects answered that the biggest barrier for solar-integrated architecture was the lack of client interest. At the same time, all architects mentioned that they experienced that solar products – solar cells and panels – were too expensive at the moment.

Investment costs I would say [is the biggest barrier]. It is expensive and the cost coverage is very uncertain; how do you get [the investment] back? I don't think architecture is the obstacle (architect #3)

Architects experienced that clients seemed to have a lot of prejudices when it comes to sustainable/solar-integrated architecture. There is also a significant difference between clients; the small-scale private client has other means and incentives than the larger-scale professional clients.

#### Financial incentives

Several architects mentioned that the connection between the two main barriers – lack of client interest and expensive active solar products – is a result from the short-term benefit culture within the property development and building industry. When the payback time of active solar products is

over 5–10 years, property developers do not see the need to invest in them on financial grounds. Many architects often experienced that property developers were very positive at the beginning of the design process about having active solar products in the building, but that later on in the process, active solar products were considered too expensive. None of the architects mentioned the costs related to the passive application of solar energy.

Some architects tried to convince clients to integrate solar energy by performing not only energy calculations, but also by taking into account investment costs and the reduction of energy use in the building. The fact that clients in the end decided not to integrate active solar products in the building was experienced by architects as disappointing.

Several architects mentioned that the basic grounds for this lack of client interest lies within our society and economic system. Many property developers are only focussed on making profit quickly. In contrast, architects saw a need for more input from the government. Some architects saw energy certifications as a good development for clients who not only focus on financial issues, but also on their 'image'. Subsidies were mentioned by architects as an instrument of the government to increase the penetration of solar products in buildings. Architects also praised the initiatives taken by local authorities to stimulate the use of solar energy, for instance, by stricter building regulations or by competitions. In the process, all stakeholders were forced to do something extra.

Another problem in convincing the client was the fact that property owners and building contractors have a long tradition of building in a certain way. A new way of building, for instance, is needed when building passive houses, and is therefore considered as (financially) risky, even though these techniques have been proven for quite some time.

It is important to convince the property developers, because they have arguments why not to build passive houses. One is that it is not done before in Sweden, and that they are not the one who should be engaged in 'experimental building'. In Sweden, the first passive house was built ten years ago, so it is not strange. There are so many prejudices about [passive housing]. That makes it tough sometimes (architect #9)

#### *Non-financial incentives*

The majority of architects had been involved in projects where the client was eager to have solar-integrated architecture. In those cases, the client often wanted to show that they took the subject seriously; environmental considerations had to be clearly visible in the building.

Projects built in the beginning of the 2000s, and the ones paid by a non-professional client showed this involvement often in a *non-quantifiable* way, for instance, by means of solar panels being expressive architectural elements. More recent projects, and the projects paid by professional clients, often had a *quantifiable* way of showing their involvement; several certification systems are now being adopted by real

estate developers to show their future tenants that they care about sustainability. Architects got clear assignments saying that a building needed to comply with an additional set of building standards. When the building is built according to these specific building standards, the building is rewarded. With this reward, property developers are able to profile themselves as being sustainable and this is indirectly a financial incentive.

What I have noticed sometimes was that a client took a decision that was not economically advantageous, (but) that they can put [the costs] on their marketing account (architect #6)

Energy certified or not, certain projects started serving as an example of sustainable/solar-integrated architecture and/or urban planning. One architect, who was involved in a now well-known sustainable urban planning project, had given many lectures locally and internationally about the project. The involved architectural office had clearly got new assignments based on the fact that they had designed this project.

The interest for these issues has been very big in Scandinavia and north European countries. We get foreign visitors to the project every day. I don't know how many newspapers I have met and how many interviews I have given. We work now in China and Russia, we have done studies in England. It makes it profitable in that way (architect #3)

#### *Solar products*

The majority of the architects experienced a limited choice of attractive solar products on the actual market. However, most of them observed a big development of new products, mainly in the area of solar cells. The recent emphasis on sustainability has made that development possible and necessary.

Architects expressed that they would like to see more solar products which can be really integrated in the building, instead of building added products. This would not only be preferable for the architecture of the building, but replacing building materials and components with solar products makes it financially more attractive as well. Many architects expressed that the current, limited offer of products is also limiting an aesthetically pleasing integration of solar products. Architects would like to see solar products as a building material where colours, sizes, shape and other features could be changed easily. With the right detailing, architects could really integrate them into buildings. One architect mentioned that solar products should be considered by architects as all other building material, with its own characteristics, but this requires a general increase in knowledge.

... interesting is the border between products and material. As an architect, you really want to work with a material, to choose dimensions yourself, more than having a finished product which is going to be placed somewhere (architect #2)

## Conclusion

With regard to solar-integrated architecture and its design process, the following main issues were identified as important by the interviewed architects:

- All involved actors should strive for a sustainable project:
  - *the client*: to make it financially possible;
  - *the engineers*: to make it technically possible;
  - *the municipality*: to make it legally possible;
  - *the architect*: to make it into an attractive, functional and healthy building pleasant for its inhabitants.

However, it was not experienced exactly as that. As teamwork and collaboration become crucial and more intense and necessary, it gets more important for all actors to speak 'the same language'. Architects experienced a gap between engineers and architects because of different backgrounds and difficulties of communication. With the need for more clever, energy-efficient buildings, it could be said that architects need more engineering skills while engineers need to gain more architectural skills. As we see that IDP is becoming a more common and necessary design method, it should perhaps be introduced in the education. Learning how to successfully collaborate within the design team should become part of both the architectural curriculum as well as the engineering curriculum in order to reduce problems in future IDPs.

- Clients did not prioritize solar-integrated architecture. This was mainly due to a resistance of investing in active solar technologies which did not provide short-term profit. Architects mentioned that a change of ownership's type – one which prioritizes a long-term commitment – would stimulate the integration of active solar technologies. This change was seen possible if it would be stimulated by subsidies or other financial incentives. Green building certification systems were often seen by architects as a positive influence on the building process, because clients will more easily invest in sustainable (solar) aspects for the sake of marketing. However, a certain caution is needed when it comes to certification systems. For instance, the LEED certificate gives little incentive for passive solar energy (as it is only considered as part of the operational energy calculation and not as on-site renewable energy) and a LEED certification is no guarantee for a better energy performance (Shaviv 2011).
- All interviewed architects mentioned to have used rules of thumb as a design tool. Those rules provided them basic information and would orientate architects in the right direction in the early design phases. Architects do use rules of thumb on other aspects during the

very early design process, for instance, for estimating approximate size of structural elements, as these sizes can greatly affect spaces within the building. Structural engineers make more detailed calculations in the later design phase and will adjust the sizing according to these. Rules of thumb regarding energy aspects can also help architects in the very early design phase but they do not substitute energy simulations, which are needed at later stages (Granadeiro *et al.* 2011). In some cases, advanced BPSs were carried out by (building service) engineers in order to provide more information for the architects and engineers to work with, but those advanced simulation were never performed by architects.

- There is a lack of aesthetically attractive active solar products. Most of the architects would like to consider active solar systems more as a building material, with the possibilities to change colour and dimensions.

## Limitations

One limitation in this research can be the limited number of interviewed architects. However, earlier researches show that it is possible to draw conclusions from a limited number of case studies (Flyvbjerg 2006, Ruddin 2006).

Another limitation of this study can be the ambiguity of the terminology within the field of low-energy buildings and solar-integrated architecture. Even though architects were asked to describe the term 'solar-integrated architecture' and its relation to sustainable architecture, it was not always clear as to what the term contained. This was especially the case in the projects where there was no active application of solar energy (solar cells, panels) but where architects worked with the passive application of solar energy (orientation, prevention of overheating, daylight).

Another limitation can be the fact that only architectural offices were visited in the bigger cities in Sweden.

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