Chapter 3
Integrated Design Concepts and Tools

It is critical to make the decision to build a green building early in the design and construction, or retrofitting and refurbishment process in order to maximize the green potential, minimize redesign, and assure the overall success and economic viability of the green elements of the building project. Making a commitment to build green and establishing firm environmental objectives for the project must be done as early as possible because opportunities for incorporating green technologies and design solutions become less and less available and increasingly costly to implement as the project design and construction process progresses.

Building a green building is not just a matter of assembling a collection of the latest green technologies or materials. Neither is it sufficient to just follow the building codes, standards or rating system guidelines that are available for green buildings. It is essential to ensure that choices made for green building technologies and measures are commensurate with the site selection, building orientation in order to effectively meet the design goals. There are various factors to be considered during the design of a green and smart building as shown in the Fig. 3.1.

3.1 Integrated Design Process

Integrated design or whole-building design is a process in which every element of the design is first optimized and then the impact and interrelationship of various different elements and systems within the building and site are re-evaluated, integrated, and optimized as part of a whole building solution. For example, interrelationships between the building site, site features, the path of the sun, and the location and orientation of the building and elements such as windows and external shading devices have a significant impact on the quality and effectiveness of natural day lighting. These elements also affect direct solar loads and overall energy performance for the life of the building. Without considering these issues early in the design process, the design is not fully optimized and the result is likely to be a very

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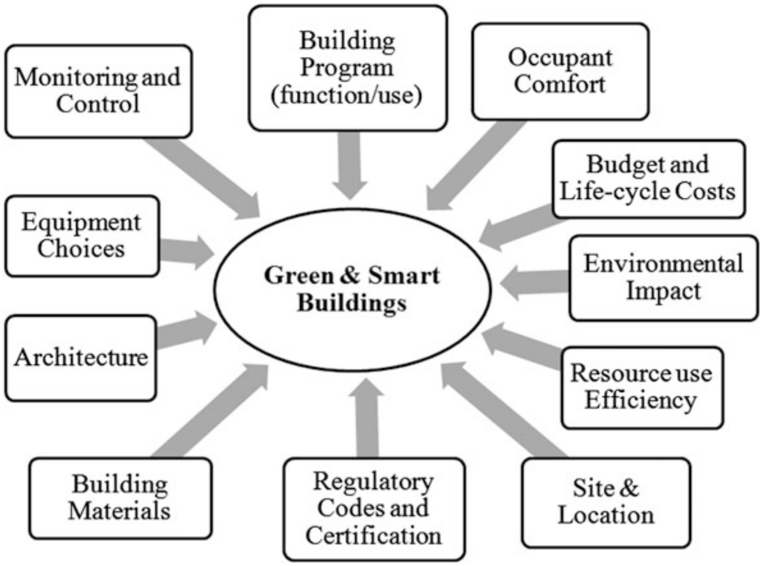

Fig. 3.1 Factors affecting green and smart building design

inefficient building. This same emphasis on integrated and optimized design is inherent in nearly every aspect of the building from site planning and use of on-site storm water management strategies to envelope design and detailing and provisions for natural ventilation of the building.

The integrated design process mandates that all of the design professionals work cooperatively towards common goals from day one. This is often easier said than done as each professional and stakeholder have their own perspective, goals and performance targets for the building design and quite of a few of them could be competing or contradicting with each other. However, by establishing communication and collaboration early in the project, there will be less “surprises” that cause delays and have higher cost implications. Table 3.1 highlights the differences between a traditional building design approach and an integrated design approach.

One useful method to enhance the communication between the various stakeholders of the building is to conduct a joint workshop or what is often referred to as a ‘Integrated Design Charrette’. A charrette can be viewed as a focused and collaborative brainstorming session held at the beginning of a project with a multi-disciplinary team that encourages an exchange of ideas and information and allows truly integrated design solutions to take form. Participants are encouraged to cross fertilize and address problems beyond their field of expertise. The charrette is particularly helpful in complex situations where many people represent the interests of the client and conflicting needs and constituencies. Participants are educated about the issues and resolution enables them to ‘buy into’ the schematic solutions. A final solution isn’t necessarily produced, but importantly, often interdependent,

Table 3.1 Difference between a traditional and integrated design approach

Traditional design approach	Integrated design approach
The project team members are involved sequentially based on their professional specialization	A diverse set of inputs from all project stakeholders is sought right from the start of the project
Project intensity is increased over time with less time spent at early design stages	The intensity of project in the early stages is significant with brainstorming discussions, design charrettes and planning workshops/meetings
The building systems are considered and optimized in isolation, often resulting in over-sizing due to design buffers	The project team adopts a whole system thinking approach considering overall building performance
Energy modeling and building simulation is done towards the end to assess performance and/or meet regulatory requirements	Energy modeling and simulation is done on a continuous and iterative basis throughout the design process to meet performance goals optimally
There is often a strong focus on reducing upfront capital costs	A life-cycle cost approach is taken to achieve better total cost savings throughout the building life cycle

issues are explored. The following are the desired outcomes from a successful Integrated Design Charrette (NREL 2009):

- Establish a multidisciplinary team that can set and agree about common project goals. See Fig. 3.2 on the areas of expertise desired from the multidisciplinary team.
- Develop early consensus about project design priorities.
- Set project performance goals.
- Generate quantifiable metrics to measure the final energy and environmental outcomes against the performance goals.
- Provide early understanding of the potential impact of various design strategies.
- Initiate an integrated design process to reduce project costs and schedules and obtain the best energy and environmental performance.
- Identify project strategies to explore with their associated costs, time considerations, and needed expertise to eliminate costly surprises later in the design and construction processes.
- Identify partners, available grants, and potential collaborations that can provide expertise, funding, credibility, and support.
- Set a project schedule and budget that all team members feel comfortable following.

Figure 3.3 shows a photo from a real design charrette that indicates the participatory nature of such workshop, which is crucial in achieving its success.

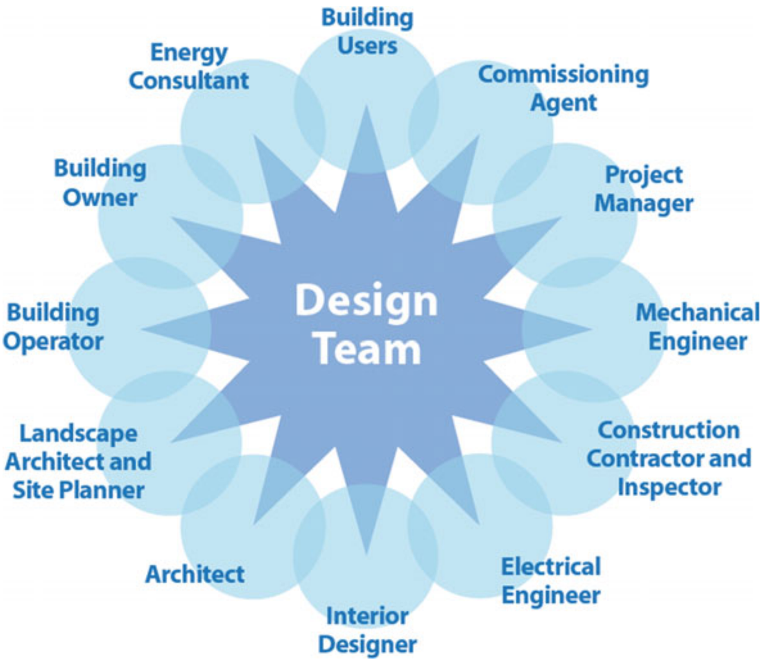

Fig. 3.2 Areas of expertise to be represented in a Integrated Design Charrette (NREL 2009)

Fig. 3.3 Photo taken during an Integrated Design Charrette (ERI@N, Singapore 2013)

3.2 Building Information Modeling

Tools such as Building Information Modeling (BIM) are very useful during the design stage of the building to get a fairly accurate visual representation of the building and document its design features in an easily accessible manner. BIM is a is a digital 3D model of all aspects of a building including architectural, structural and mechanical elements. BIM has the potential to change the role of drawings for the construction process, improve architectural productivity, and make it easier to consider and evaluate design alternatives. BIM also aids in the process of integrating the various design professionals to find problems like ducting and wiring systems that are drawn in the same location, further encouraging and demanding an integrated design process.

BIM is a substantial enhancement over the previously used Computer Aided Design (CAD) tools in terms of functionality and most importantly allowing collaborative designs. It differs from the previously popular architecture drafting tools by allowing the addition of further information such as time, cost, manufacturers' details, sustainability and maintenance information, etc. to the building model. With everyone working within one file it is easy to see what information is missing and what areas of the design need to be focused on or refined and hence significantly aids the decision making process. See Fig. 3.4 for a screenshot from a BIM tool used on a computer.

There are various commercially available BIM software programs and the following list shows some popular BIM software programs and providers:

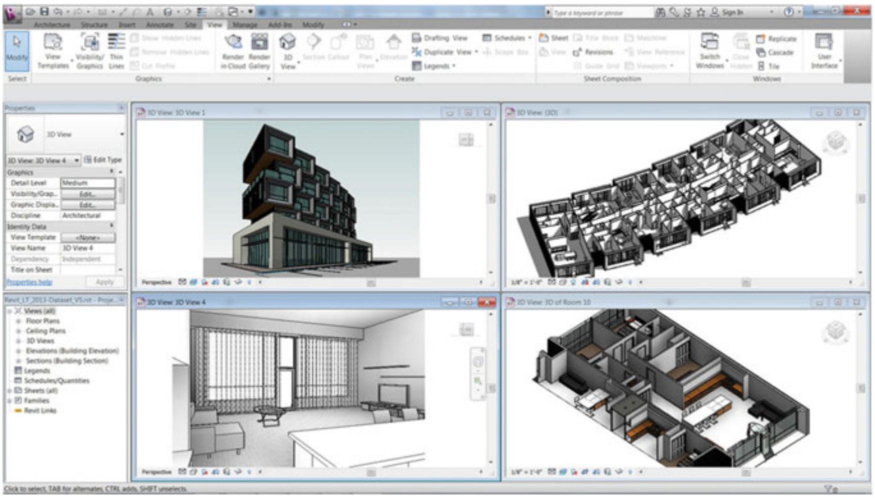

Fig. 3.4 Screenshot from a BIM software tool

1. Autodesk provides various BIM software programs such as Revit for architectural design, Mechanical, Electrical and Plumbing (MEP), and structural engineering as well as cloud based solutions such as BIM360. Visit for more information: http://www.autodesk.com/.
2. Bentley Systems also provides a suite of BIM tools: https://www.bentley.com/.
3. DProfiler by Beck technology: http://www.beck-technology.com/.
4. ArchiCAD by Graphisoft: http://www.graphisoft.com/.
5. Vectorworks Designer by Nemetschek: http://www.nemetschek.net/.
6. Tekla Structures: http://www.tekla.com/.
7. Google Sketchup Pro: http://www.sketchup.google.com/.
8. Affinity by Trelligence: http://www.trelligence.com/.
9. Vico Office: http://www.vicosoftware.com/.
10. Digital Project by Gehry technologies: http://www.gehrytechnologies.com/.

3.3 Energy Modeling and Simulation

Energy modeling and simulation tools allow the design team to evaluate the energy performance of the building in the virtual environment considering its geometrical model, design parameters, occupancy schedules and local weather conditions. The output of the energy modeling is typically the energy consumption of the building simulated at time intervals (typically hourly) throughout the year. It could be used as a tool to compare and contrast various technologies for energy efficiency of the building at the design stage. This will allow the design team to choose appropriate building technologies vis-a-vis their energy savings potential and cost implications. Figure 3.5 shows a screenshot from the energy modeling software used to perform sun path analysis for buildings.

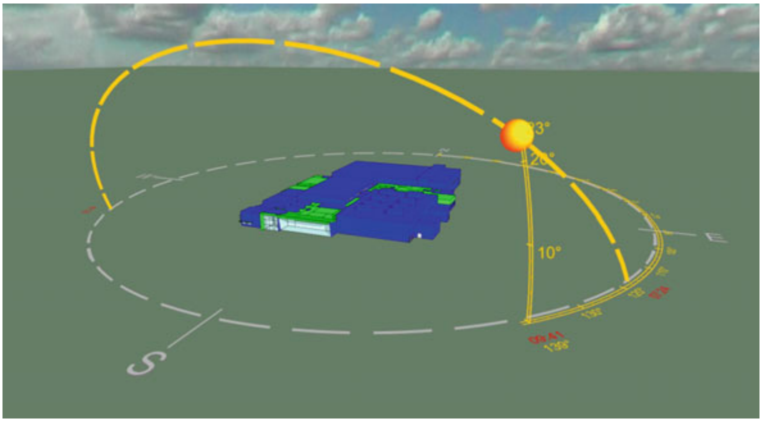

Fig. 3.5 Screenshot from energy modeling software showing sun path analysis (*Source* IES)

Table 3.2 Benefits of energy modeling at various stages of building development (adapted from AIA 2012)

Building stage	Energy modeling outputs
Concept design	✓ Define goals and requirements of the project based on early modeling results ✓ Experiment with options for building orientation, massing and envelope constructions ✓ Explore ways to reduce loads ✓ Get the design team together to assess integrated system performance and make design decisions based on the results
Schematic design	✓ Create a baseline energy model ✓ Test the effectiveness of different energy conservation measures and options before selection and implementation ✓ Determine the most cost effective solution to reduce energy consumption to the lowest
Design development	✓ Finalize baseline model to compare against proposed design ✓ Create proposed models with system alternatives to choose from ✓ Provide annual energy use charts and other performance metrics for comparing baseline versus proposed design ✓ Evaluate specific products and technologies with refined data and details
Construction documents	✓ Create documentation needed to accompany energy model results for code compliance and for green certification requirements such as LEED
Commissioning and post-occupancy	✓ Use results of the as-built model for commissioning ✓ Collect metered operating data to create a calibrated model to share with outcome-based database

Although energy modeling is primarily used in the design stage, it can also be very useful in the other stages of the building development. Table 3.2 highlights the benefits and outputs of energy modeling at different stages of development of the building. Design, performance, and energy modeling are iterative processes. Initial models address fundamental design parameters, including the building envelope, orientation and massing, typically without including mechanical or electrical systems in a manner that provides crucial, and sometimes surprising, design guidance. As models develop, they provide feedback to the design team on how the form, orientation, programmatic strategies, and other variables will likely affect the project's performance in terms of energy, daylighting, comfort, and other design characteristics. E.g. it is useful to perform a dynamic shading analysis of the building structure to understand the ingress of heat and daylight into the building at various times and seasons during the year. This facilitates the choice of building orientation, form factor and envelope parameters.

It is important to note that Building Energy Modeling is a computer program and the accuracy of results would largely depend on the inputs provided to the model. In this context, one should be mindful of the expression 'garbage-in-garbage-out'. It is hence crucial that the right set of inputs are provided to the energy modeling tool. Table 3.3 lists the typical inputs provided to the energy modeling tool. Some

Table 3.3 Typical input parameters required for building energy modeling

Model input set	Input parameters
Location specific	• Local climate data (typically imported via a weather file in the software) • Interior conditions and set points
Architectural massing and form	(Typically imported through 3D geometrical modeling tools such as Google Sketchup) • Building shape and orientation • Total floor area • Number of floors and thermal zoning • Floor-to-ceiling height
Building envelope	• Window-to-wall ratio • Area, orientation, solar absorptance, and thermal transmittance of all opaque building surface • Area, orientation, solar heat gain coefficient, visible light and thermal transmittance, and shading of all glazing components • Mass of building components • Infiltration rates
Thermal and electric loads	• Lighting intensity • Plug loads intensity • Sensible and latent (moisture) loads from people and other equipment • Pumps, motors, fans, elevators
Schedule of operations	• Lighting schedules • Plug-load schedules • Occupancy schedules
Mechanical and Electrical (M&E) systems	• Cooling/Heating system type, including the source, distribution, and terminal units • Ventilation system type • Fan and pump inputs • Economizers and/or heat recovery systems • Domestic hot-water system • Specialty systems (e.g. fume hoods, exhausts) • Renewable-energy systems

user-friendly software programs have built-in industry standard defaults of these input parameters that speed up early model creation.

The past decade has seen remarkable growth in the Building Energy Modeling industry, primarily driven by more stringent building energy efficiency standards and a growth in voluntary building energy certification programs. There are now various energy modeling and simulation tools that are commercially available to perform the functions as described above and the popular ones are listed below for quick reference:

1. EnergyPlus by the U.S. Department of energy (free tool), available at: https://energyplus.net/.
2. IES Virtual Environment (VE): http://www.iesve.com/.
3. eQUEST, quick energy simulation tool: http://www.doe2.com/equest/.
4. Autodesk Green Building Studio: https://gbs.autodesk.com/GBS/ (cloud based).

5. TRNSYS: http://www.trnsys.com/.
6. DesignBuilder: http://www.designbuilder.co.uk/.
7. Radiance: Lighting simulation tool: http://www.radiance-online.org/.
8. OpenStudio by NREL: https://www.openstudio.net/ (open source, free interface tool using EnergyPlus and Radiance.
9. Dymola: http://www.3ds.com/products-services/catia/products/dymola.
10. Autodesk Revit (previously known as Ecotect).

3.4 Advance Optimization Tools

It can be extremely difficult to optimize a building's energy consumption or cost-effectiveness due to the vast array of parameters that can be changed in the energy model during the design phase. To maximize the energy-savings potential while minimizing the costs of a building, there are advance tools available such as Opt-E-Plus (from NREL) and GenOpt (from Berkeley Lab). Such tools automatically run thousands of simulations and identifies design options that provide the most economical energy savings. The design options are based upon parameters chosen by the user that are allowed to vary within specified ranges, and all possible combinations are plotted on a chart of percentage energy savings plotted against percentage cost savings in order to outline optimal design strategies. An example results chart is shown in the Fig. 3.6.

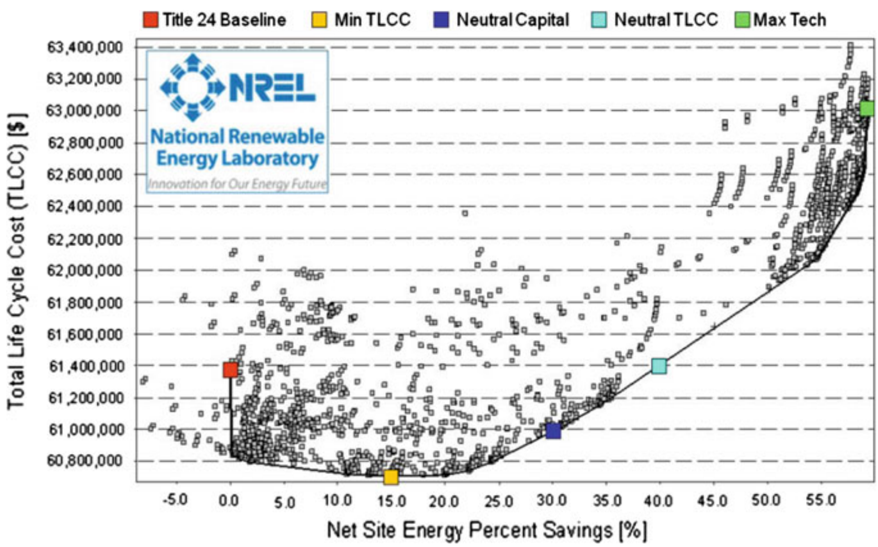

Fig. 3.6 Example results from NREL's Opt-E-Plus advanced optimization tool for energy modeling (NREL 2009)

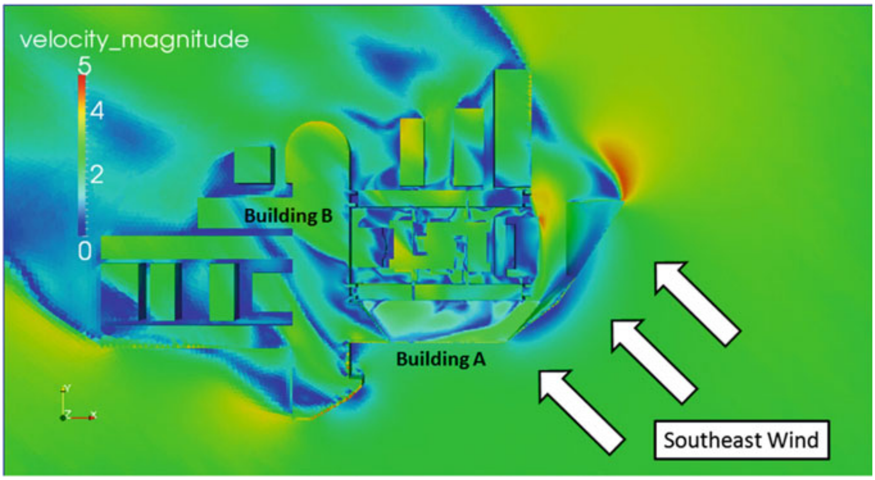

Fig. 3.7 Screenshot from Computational Fluid Dynamics (CFD) modeling software used for airflow analysis across neighborhood buildings (ERI@N, Singapore)

3.5 Airflow Modeling

Apart from energy modeling, it is sometimes important to understand the air flow and distribution patterns for buildings: both outside and inside. The building form and shape can affect how air flows through the building and across neighboring developments into the building. This is an important consideration for natural ventilation and can significantly reduce costs of air-conditioning provisions. There are Computational Fluid Dynamics (CFD) tools available that can help simulate the air-flow patterns within built-spaces as well as for whole building estates (see Fig. 3.7 for illustration of airflow modeling analysis in buildings). The popular tools used for this purpose are listed below for quick reference:

- Fluent by Ansys: http://www.ansys.com/.
- FloVent from Mentor Graphics: http://www.mentor.com/.
- Comsol Multiphysics modeling software: https://www.comsol.com/.

References

AIA (The American Institute of Architects) (2012) An Architect's guide to integrating energy modeling in the design process

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