
An Energy Conscious Architectural Design: The Solar Responsive Envelope and Form Finding Approach

Ekkachai Mahaek, Ph.D.

Faculty of Architecture, Chiang Mai University

ABSTRACT

From the world energy crisis in 1973 to present global warming, there is a growing emphasis on integrating energy-efficient strategies in architectural designing to reduce fossil fuel consumption and its associated environmental pollution. In large part, the lack of effort by mainstream designers is due to the complexity in building's energy conscious concepts and the difficulty to visualize or quantify energy consumption. Conventionally, this task would be conveyed to the building system's engineer, normally delaying project after the basic architectural concepts have been completed. It is the assumption that the lack of tools to characterize the beneficial or detrimental characteristics associated with site energy resources during the preliminary design phase makes efforts to reduce a building's energy consumption more difficult. An effective simple tool and method should be available to assist architects at the beginning of the design stage.

The sun plays a major role in the design of human dwelling; requiring appropriate responses for ventilation, cooling, heating, and lighting. Architecture should be influenced by the relationship of the sun and building configuration. The full spectrum of solar radiation provides light and heat to the envelope of buildings. This solar radiation and its attendant luminance have a direct effect on the amount of energy a building will consume. If an architect can define, or map, the intensity of solar energy on the potential building site, and use this information to characterize the levels of *solar insolation* available to be accepted or rejected into the building, a more energy efficient envelope or form of the building can be established.

This paper will discuss an approach to develop a potential three-dimensional architectural form based on an insolation map related to the design site. The proposed computer-based programming procedure will be referred as *Solar Effective Envelope Design Advisor (SEEDA)*. The three-dimensional form is determined by integrating three types of computer-generated models. These models are the *Solar Envelope Volume* model based on Prof. Ralph Knowles's principles and related research, the *Buildable Volume* model based on design constraints, which will represent an optimum volume for the building; and the *Shading Condition Volume* model based on shade

producing objects that surround the adjacent site. Once the integrated three-dimensional volume is created, the levels of insolation and luminance at the volume's surface can then be determined and quantified, hence, the solar responsive envelope and effective form will be defined.

Keywords

Buildable Volume: Allowable volume of building mass generated from the total gross floor area that can be built on the designed site

Shading Condition Volume: Shading volumes of surrounding buildings that project below the solar spectral beam

Solar Envelope Volume: Ralph Knowles's definitions for the maximum volume of the site that can be built and will not cast a shadow onto the adjacent sites

Solar Insolation: The incident solar energy per unit area over a period of time

I. INTRODUCTION

1.1 Background

The pollution of the environment together with limited amounts of nonrenewable energy have created a serious situation and caused an environment crisis. For the last decade, an average of 60% per year of all electrical energy generated from nonrenewable resources is used in the construction industry [NREL, 2001]. In the USA, the cost of energy consumption in buildings is approximately \$250 billion or 35% per year of total energy resources [Stein, 1992]. Therefore, energy efficiency and environmentally compatible design must become an important strategy of every building project design. Though the sun has direct impact on an urban settlement and provides plentiful and clean energy, most architects still allow subjective reasons to dictate the design rather than complying with an energy conscious design criterion. This is because of the lack of understanding of complex theories of solar energy design and also the limited availability of simple design tools for the preliminary-design stage. The Solar Envelope principle, the effective principles invented by Professor Ralph L. Knowles, is one of the design methodologies which can help a designer define the particular built form of any particular site, which is not give shade on the adjacent sites.

This research uses Knowles's Solar Envelope principle in three stages. First, it eliminates the limitation of solar envelope volume by assuming an allowable to restriction of the local region called a Maximum *Buildable Volume*, taking into account the built form. Second, it considers the overshadowing of the

site by the shading volumes of surrounding objects below the solar spectral beam, which will be called *Shading Condition Volumes*. Third, it projects the *Solar Envelope Volume* on to the *Buildable Volume* above the overshadowing line of the *Shading Condition Volumes*, instead of using the footprints or site boundary line of the surrounding objects as Knowles does. To improve the cumbersome conventional technique of projecting solar radiation, Solar Envelope plotting, solar insolation calculation, computer-aided design drawing and programming technique are introduced as a medium for generating the geometrical volumes and computing solar insolation levels.

1.2 Statement of the Problem

This research, building on the Solar Envelope Principle, proposes to find a simple but effective method to quantify a physical solar energy impact in order to improve architectural design. Conditions associated with solar-energy-responsive design are investigated. Some internal factors such as urban and landscape context, internal space expression, and structure expression are direct and obvious, but some external factors such as bioclimatic expression, individuality, monumentality and tourism attraction, economic aspects and design trends are more subtle (Figure 1.1). There are also the reasons associated to the energy issues in building design that require the development of a design tool at the early design stage. These issues are:

- 1.2.1 Energy Resource Extinction and Associated Ecological Problems
- 1.2.2 High Cost of Energy-saving Technology in Building Design Practice
- 1.2.3 Lack of Appropriate Design Tools and the Complexity of Current Tools
- 1.2.4 Misinterpretation in Decision Making of Design Process

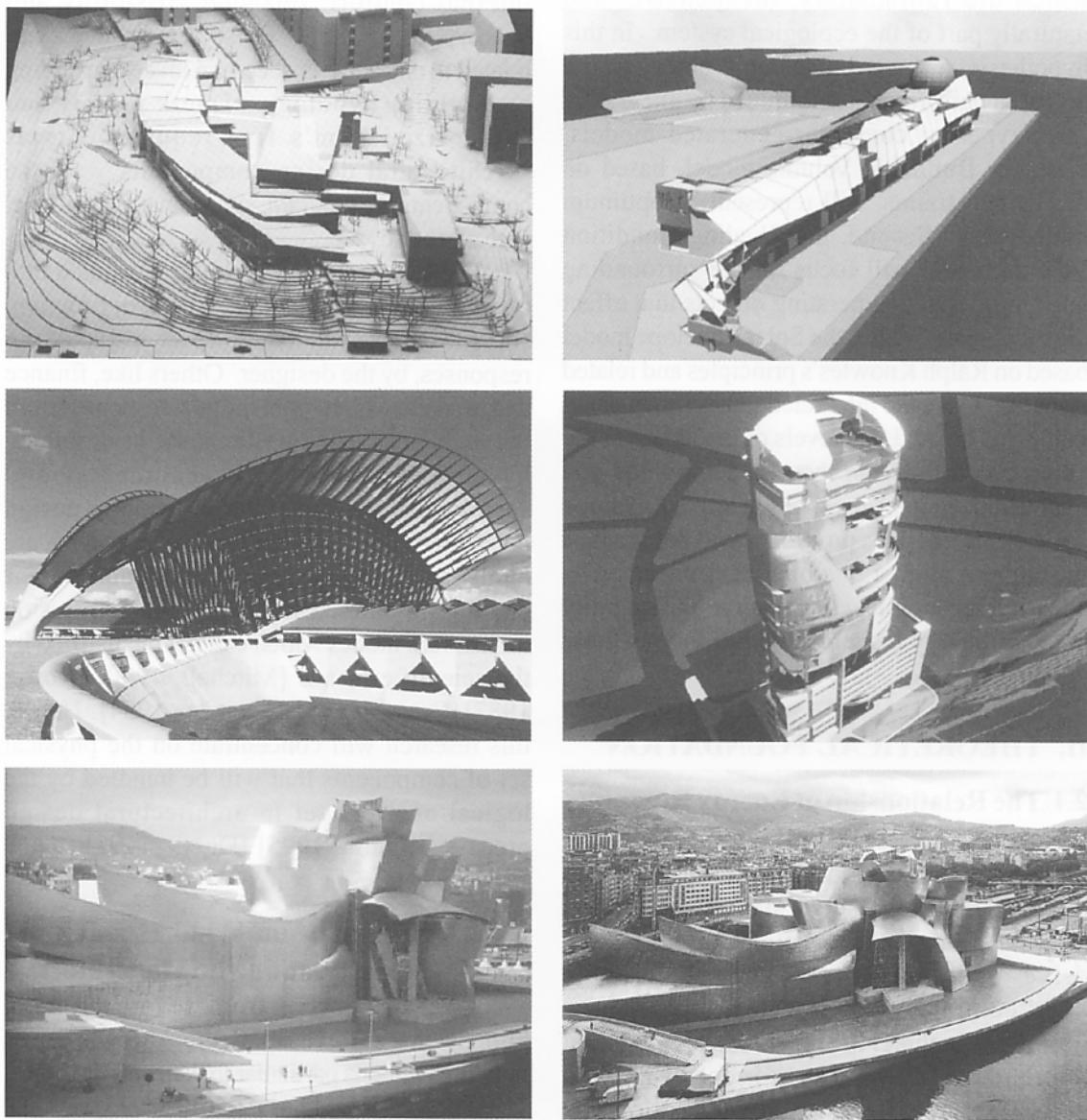


Figure 1.1 Example of approach-influence concepts and expressions that impact architectural design
(From left to right and top to bottom)

- a. Urban Context: Architecture Building, University of Cincinnati, Ohio, USA, Peter Eisenman
- b. Internal Space: Warehouse C, Nagasaki, Japan, ROTO
- c. Structure: Rhone Alpes TGV Station, Lyon, France, Santiago Calatrava
- d. Bioclimatic: Hitech Niaga Tower, Kuala Lumpur, Malaysia, Ken Yeang
- e. and f. Monumental Attraction: Guggenheim Museum, Bilbao, Spain, Frank O. Gehry

1.3 Research Hypothesis

A solar-energy-responsive strategy can be designed and initiated in both active and passive modes. This research hypothesis will concentrate on the passive mean strategies which are rudimentary, inexpensive, and naturally part of the ecological system. In this hypothesis, a three-dimensional model of the potential built-form is determined by integrating three types of computer-generated models. First, the Buildable Volume model, based on design constraints, will represent an optimum built-form. Second, the Shading Condition Volume model will focus on the surrounding buildings' shade-generating objects that affect the design site. Third, the Solar Envelope model based on Ralph Knowles's principles and related research. Once the integrated three-dimensional volume is created, the levels of insolation at the volume's surface can then be determined and quantified, hence, the Solar Effective Envelope will be created. This procedure will help reduce the amount of energy a building consumes by allowing the architect to visualize and quantify all solar energy resources within the potential building site.

II. THEORETICAL FOUNDATION

2.1 The Relationship of Energy Resources and Building Design

Human translate regional climatic differences into distinct local forms and details. There are three major and direct influences that drive energy-efficient and sustainable architectural design development. These influences include: the inevitable extinction of nonrenewable resources, or fossil-derived energy resources forecast, unreliable prices and supply of major energy resources, especially oil, and a decline in health associated with the high level of pollution and temperature in environment due to excessive building energy consumption [Lechner, 1991] [Ander, 1995] [Yeang, 1996].

2.2 Environmental and Energy Conscious Approach in Architectural Design

In architectural design, there are five groups of fundamental requirements. These requirements are functional use, external orientation, internal comfort, financial possibility and beauty [Lam, 1986]. These requirements are related to one another at certain levels depending on building typology. Duerk [1993] had categorized Lam's five requirements as "architectural design components". These components are program, site, climate, economic, and aesthetic.

The five components can be separated into two groups. In architectural design, program, site, and climate will require direct, manipulative responses, by the designer. Others like, finance and aesthetic will require indirect responses from the architect. The questions set in designing have to do more with economical and sociological theories than systematic design decision-making. These types of problems are hardly solved by the logic answer, due to their cultural variables, test, and personal impression in different modes which can not be justified by the scientific means [Mitchell, 1990] [Rowe, 1987] [Cross, 1984] [Alexander, 1964]. Hence, this research will concentrate on the physical set of components that will be handled by the logical answers set in architectural design process [Kumlin, 1995] [Duerk, 1993] [Pena, 1987] (Figure 2.1).

2.2.1 Climate: Sun, Wind, Humidity, & Precipitation, the Moderators.

To survive from severe climate, humans have developed the knowledge of building methods particular to theirs civilizations. The first shelter was a roof [Grillo, 1975]. People in different climatic regions also have their unique shelter roof forms and technologies according to the regions conditions [Olgyay, 1963] [Daniels, 1995]. Olgyay [1963] had elaborated this in his previous study about the history of climate's relationship with dwelling. We can observe many of these examples from the previous works of modern architects, such as Gropius, Corbusier, Alto, Khan and Wright.

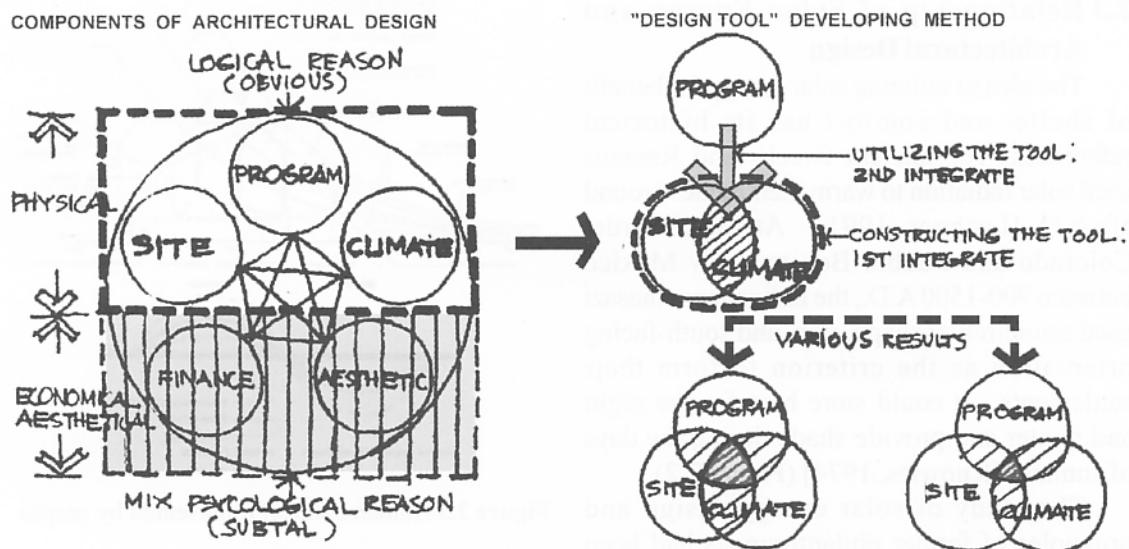


Figure 2.1 Proposed design tool components and developing method

2.2.2 Site: Location, Geography, Surrounding, Orientation, Conditions.

The conditions of the site can influence and express in the characteristic of human's dwelling form and layout. Two major books of Ralph Knowles, "Energy & Form and Sun Rhythm Form" [Knowles, 1974, 1981] have shown an elaborate example and relationship of architecture and sun's influence. The first theory is the influence of solar energy on the shape and orientation of human settlement. The second one is the influence of sun's circulation in different modes and their daily and seasonal relations [Knowles, 1974, 1981].

Another important aspect of site that may have an impact on its architectural development is the regulatory constraints of different organizations which target various scales and areas of development such as zoning laws, building ordinances, or sanitary and fire control ordinance. However, they share the purpose of controlling and providing quality, security, and comfort to human life [Moore, 1985] [Lynch, 1996] [Yeang, 1996, 2000] [Chicago, 2000]. Site constraints have a great impact on

the physical development, height, volume, and shape of architecture in different areas and regions.

2.2.3 Program: Master Plan, Functions and Components, and Requirements.

The building program was not considered one of the architectural design components until 1960s [Kumlin, 1995]. Previously, architectural design practice was largely defined as parts of craftsmanship and heuristic process where architects follow the principles that had been done before. However, architects have their own methods of organizing the requirements and its relationship.

2.2.4 Relationship of Energy and Architectural Design Components.

The physical conditions of three designs components, climate, site, and program are directly related to architecture's feature and atmosphere. They are the mechanisms that drive human beings to build their dwellings. Each component may share overlapping elements, to support its architectural design.

2.3 Relationship of Solar Energy and Architectural Design

The idea of utilizing solar energy for benefit of shelter and comfort has its historical references. The ancient Greeks and Romans used solar radiation to warm their homes around 50 A.D. [Lechner, 1991]. At Mesa Verde, Colorado and Pueblo Bonito, New Mexico between 900-1500 A.D., the indigenous Anasazi used semicircular shape, step, and south-facing orientation as the criterion to form their settlements. It could store heat for the night and winter and provide shade during the days of summer [Knowles, 1974] (Figure 2.2).

The study of solar energy design and principles of former philanthropists had been reorganized and tested by the Olgay brothers of Princeton in their books, "Design with Climate" and "Solar Control and Shading Devices" while many researchers have put more emphasis on the area of solar heating and solar cooling principles, some researchers had concentrated on solar lighting.

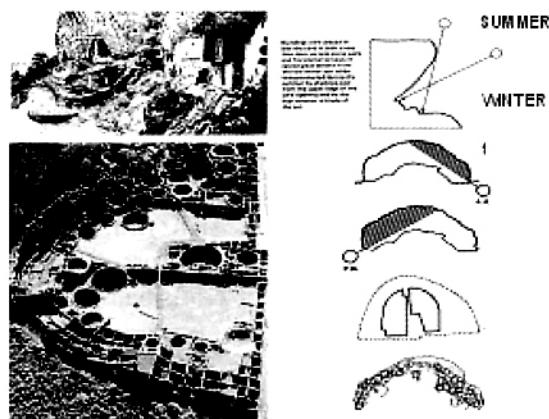


Figure 2.2 The Anasazi's dwelling at Mesa Verde, Colorado and Pueblo Bonito, New Mexico between 900-1500 A.D.; the indigenous Anasazi used semicircular shape, step, and south-facing orientation as the criterion to form their settlement

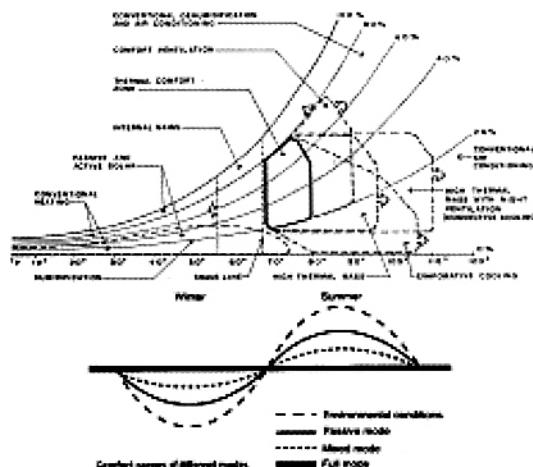


Figure 2.3 Human comfort represented by graphs

2.2 Solar Envelope Concept

Generally, the solar envelope is the largest volume within the site which will not overshadow the adjacent properties [Knowles, 1976]. Professor Knowles first developed the idea during the period of 1969 to 1971. Theoretically, the solar envelope is a geometrical projecting method to insure that residents of all building blocks share sufficient sunlight.

However, it indirectly restricts the allowable volume, which directly affects the amount of available floor area, and limits the design freedom to a required or specific maximum volume. The limitation represented by the envelope is caused by variables such as, the solar available hours, in addition to the season, latitude, and the shape and size of the building block (Figure 2.4). Knowles proposed his methods of defining a solar envelope or a construct of space and time based (of solar availability) on two premises [Knowles, 1981] (Figure 2.5). These two premises are defying the solar envelope. The first premise "...assures solar access to the property surrounding at a given site. The envelope will accomplish this by limiting on-site building heights, but the casting of unacceptable shadows." The second premise is "The solar envelope provides the largest developable volume within time constraints. The envelope accomplishes this by defining the largest container of space that would not cast shadows off-site at specified times of day the cut-off times." [Knowles, 1981].

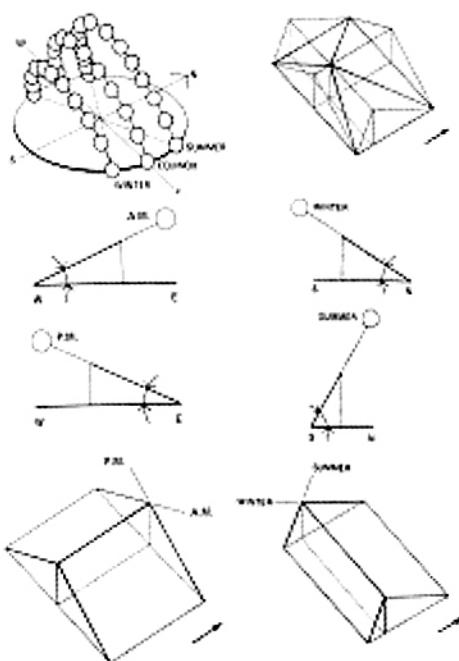


Figure 2.4 Solar Envelope Principle, Ralph Knowles.
(Source: Knowles, Ralph; Sun Rhythm Form, MIT Press, 1976)

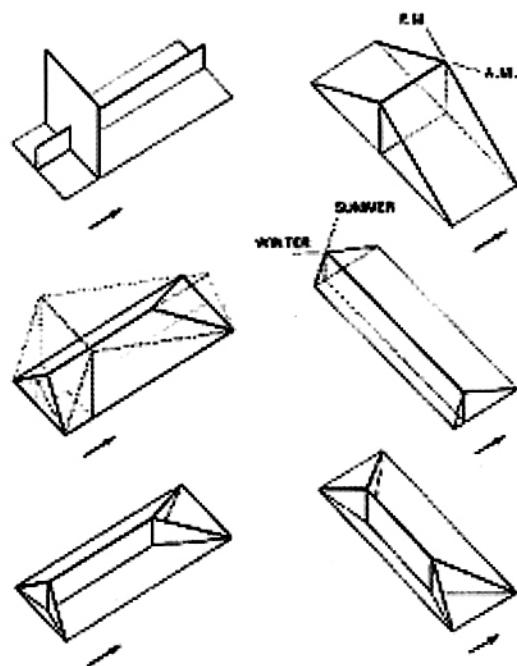


Figure 2.5 Solar Envelope Projecting. (Source: Knowles, 1981)

III. SOLAR EFFECTIVE ENVELOPE DESIGN ADVISOR (SEEDA): THE DEVELOPING OF DESIGN STRATEGY

3.1 Proposed Design Process

In the design process, a procedure should be implemented before the preliminary design stage so that its result will greatly benefit the designer's decision making in relation to solar energy responsive design schemes. It is expected that this procedure can help save time and cost, eliminate uncertainty, and assure that the design will include an effective built-forms, energy efficient envelope, and design functional zoning in the scheme (Figure 3.1).

3.2 Solar Insolation Mapping as an Architectural Design Information

Based on the architectural design components of Ander in Chapter II [Ander, 1995], an idea of the research method is to verify the influences of sun to the particular site. The outcome or solar insolation mapping can be used as the design information to achieve the energy-conscious strategy for the project.

Present day building design is complex, and requires the optimum performance for utilization and least energy consumption. In terms of passive energy approaches, buildings that are responsive to their location, environment, and orientation will generally reduce the amount of energy consumed. However, the other two design requirement paradigms, building's constraints, both federal and regional regulations, and building's functional requirement program are also two crucial design constraints. The effective design strategies then should be integrated with these three design paradigms. Within the first environment responsive paradigm, hypothesis is based on two realms of passive solar energy theories, solar heating/shading and solar daylighting, while the other realm, solar cooling, is excluded due to its theoretically, practicable only in the microclimate zone where the exists a high range of differentiate daytime-nighttime temperatures. On the contrary, the other two realms are parts of the very first priority issues in architectural design criterions that are more general and can be manipulated.

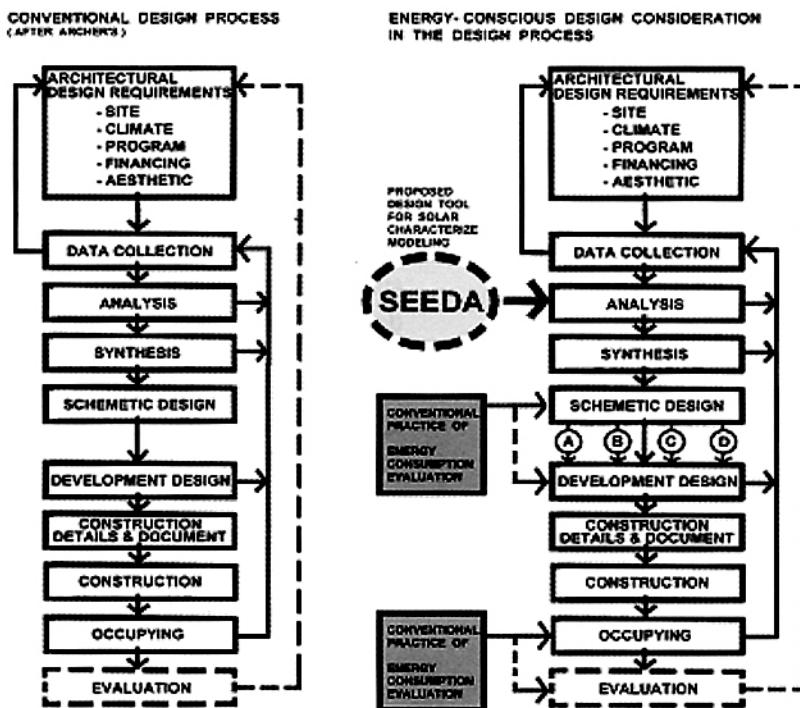


Figure 3.1 Proposed an implementing of SEEDA program before the preliminary design stage

Solar heating/shading will influence building orientation, envelope systems, and thermal transferring through internal space. Daylighting will influence envelope systems and utilized spaces design and planning. From the previous overview, we can summarize and make assumptions as the hypothesis of the research according to the discovered detailed information as follows:

Three physical components of architectural designing are climate, site, and program.

Climate and site are the conditions that are considered to be the logical queries, which require logical reasons to comply with design.

The Program component contains uncertainty and is considered to be the case-by-case basis query, which can be used for validating and comparing for effective design.

Among the factors of Climate component, the sun and its influences has the most impact on architectural feature, form, and energy consumption.

The Site component and its conditions is another cause that could have an impact on architectural feature, form, and energy similar to the sun.

Since the sun and site could cause a physical impact upon the architecture in the same manner, therefore, if one could define the virtual effect and result of sun and site to the given site, one can define the effective and responsive solar/site conditions at that site. By this hypothesis, architectural design tool can be constructed for assisting the potentially effective scheme by:

- Defining the most buildable volume, defining the obstruction areas of sun and site relationship
- Constructing the possibility of minimum to maximum Solar Envelope according to the solar/site conditions
- For visualizing and design manipulation, subtract the buildable volume of the potential schemes (minimum, maximum of solar envelope)
- For actual energy and luminance quantifying, compute the solar radiation and luminance using the equations of solar engineering and daylighting design [Duffie, 1987 & 1991] [Moore, 1985] [Ander, 1995].

The parametric comparison of other design alternatives can be investigated by the same principle, by importing the same scale model of design schemes into the measuring file to compare and visualize the schemes, and by subtracting the design scheme model to solar/site condition volume then quantify the energy/luminance of the resulting facets.

The conclusion of the research suggests that using the relationship of physical architectural design components can help us to find the method of verifying the energy effective, solar in particular, for architectural design. These methods can be very beneficial to designers for improving the design practices, time saving and cost efficient, yet providing the architecture that consume less energy and are environmental friendly (Figure 3.2).

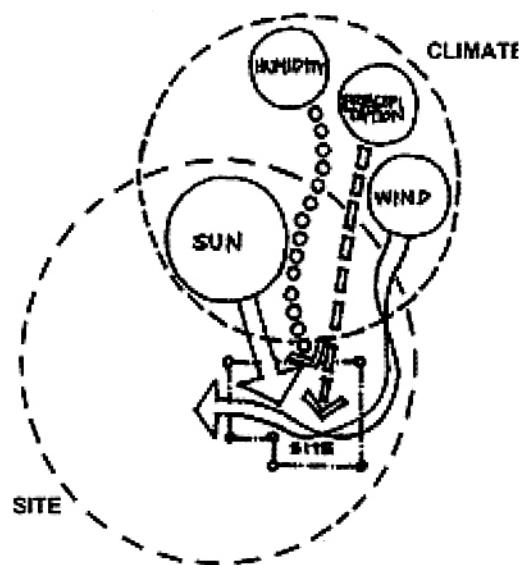


Figure 3.2 Site and climate, solar in particular, design tool concentrate area

3.3 Computer-Generated Programming as an Architectural Design Tool

Presently, many innovative designs, technologies, and strategies for energy consciousness in building design have been proposed. They can be classified into two major trends, one is nature-driven strategy, and the other is technology-driven strategy [Watson, 1993].

Nature-driven strategies include: building placement orientation, occupants mapping and zoning, solar shading and heat conduction control, environmental elements utilization, landscaping, ventilation and wind-rose control, passive cooling. Technology-driven strategies include: energy recycling, thermal comfort control, peak-load management, HVAC management, active cooling, and high performance materials and techniques implication. In professional practice, both trends have influence on building design. In fact, the nature-driven strategies are more economical, directly responsive to the environment, practicable, and truly sustainable. Technology should be used as an architectural tool to produce better performance design. It is used less successfully as a conceptual design tool. The improvement of design quality and design process using advance technology is more practical when used to specifically enhance the performance of a conceptual design.

This research's hypothesis can be validated by development of the SEEDA model by an interactive programming Design Toolkit that will be written with the AutoLisp language and, if necessary, interface with the Visual Basic language. AutoLisp language is the fundamental language that is used for writing the routine commands in the most common computer-aided design program, AutoCAD.

The AutoLisp language will be used because of its ease of use and standard format of manipulation, migrating, and interfacing among CADD programs and visualizing file formats. Three-dimensional computer generated models will be constructed as solid entities. In turn, these 3D models can be manipulated by Boolean operations, which will combine models together to result in the SEEDA. Due to the details, repetitive, computational data of the variables of each particular site need to be fed into the designing models and its conditions models (such as Buildable Volume and Solar Envelope models), programming technique is required to handle the task instead of commands-drawing.

The final computer program, which is the result of the described research, is then saved as the Design Tool Program called SEEDA.

3.4 Integrated Buildable Restrictions, Environmental Conditions, and Solar Envelope for an open-ended Design Alternative

Although integrated energy-conscious concepts in architectural design require a specific knowledge in building sciences together with the design skill, however, the SEEDA method can still provide the freedom for design approach for the designer. It is used to establish the potential volume, built-form, as a response to the solar environment at the particular location, but not necessary limited to the volume as the final design form. Designers still can make decision and treat their designs for their requirements, but with aware of solar-responsiveness information for the sites. The preconception and overemphasizing on any design criterions discussed in Chapter 3.4 can affect the proposed design's energy consumption performance. The conditions of Solar Effective Envelope are directly related to the conditions of the three types of volumes. These conditions are the building design restriction or building codes, an availability of solar radiation at the site location, the season of the year, the time of day, and the location and magnitude of obstructing objects surrounding that will shade some portion of the site. By using the combination of the three solid models component via geometrical Boolean operations, a designer can carve the solar energy effective volume and use the final volume as the guiding map for solar effective design built-form. The facets of this effective form will be able to provide an opportunity for designer to visualize, manage, and quantify the insolation levels of a potential design.

IV. SEEDA METHOD: CONCEPT, COMPONENTS, AND METHODOLOGY

4.1 Concept of the Method

The goal of the SEEDA concept is to develop a method for a designer to visualize and quantifies the availability of solar resources and solar insolation in particular of the designed site or design scheme. An availability of solar

radiation that will be defined either over a site's buildable volume would be called as the Solar Effective Envelope (Figure 4.1). The mapping of the solar insolation will use an integrated computer-generated model of three design components: Maximum Buildable Volume, Shading Condition Volumes, and Solar Envelope Volume. Using the relationship of these three component models, a building designer can determine the solar energy effectiveness of the site's potential built-form by generating a three-dimensional map based on the relationship of site's solar radiation conditions and site's Maximum Buildable Volume (Figure 4.2).

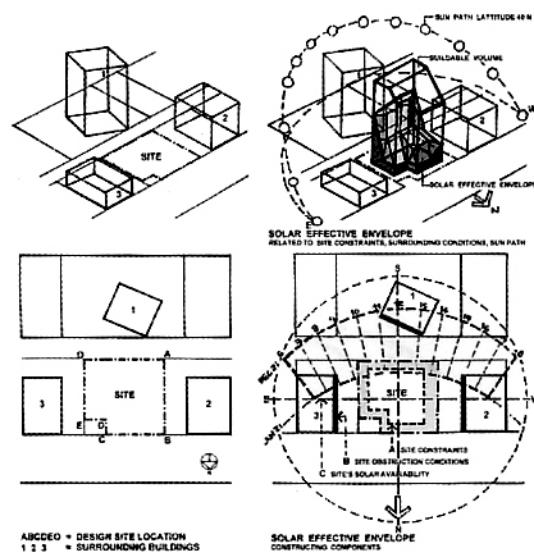


Figure 4.1 SEEDA Method: Conceptual diagram, the component factors of the hypothesis.

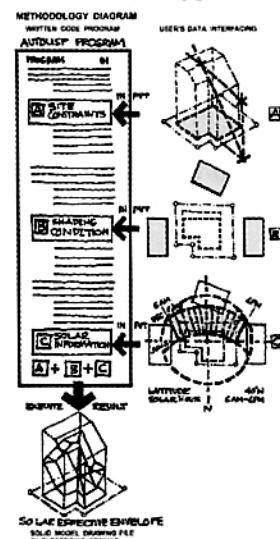


Figure 4.2 SEEDA Method: Components and methodology diagram

4.2 Components of the Method

Three types of three-dimensional models consisting of the Maximum Buildable Volume, Shading Conditions Volumes, and Solar Envelope Volume will be constructed by using a computer programming, AutoLisp language-based, generating method. The following lists are identifying factors and their conditions, if available, to classify under each component category.

(A) Maximum Buildable Volume:

The description of Maximum Buildable Volume is the optimum allowable type, shape, size, density, and height that local government agencies will allow in the construction of any building. Regulations normally include zoning laws, building ordinance, building codes, sanitation, and fire safety ordinances. Most regulations are aimed for similar purposes; they limit buildings development to provide comfort, security and good health for people. The factors of regulation involve physical constraints and will have an impact on size, shape, and form of the Maximum Buildable Volume model. Regulations are not the same from region to region. These lists are including: Site coverage, Floor area ratio (F.A.R.) or Plot ratio, Height limit restriction, Site setback, the setback distance from site boundary line, Site setback angle, the setback angle from the street, front, or egress side, Right of way, the setback distance for facilities services or fireman truck, Regional solar access and planning policy, Historical district and zoning control (see details in Figure 4.3).

(B) Shading Condition Volumes:

This design component is based on the site related conditions at difference latitude, season, assigned time periods, and the regional availability of solar radiation. Both the conditions of the site and the movement path of the sun will influence on-site shading conditions. The consequence of this variability is the impact of architectural form, solar insolation, and solar luminance levels of the potential effective form (Figure 4.4).

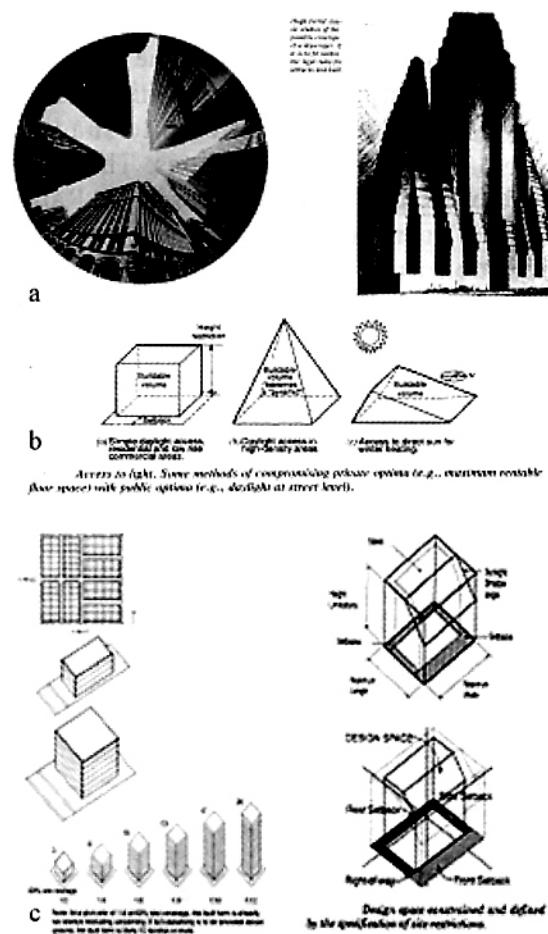


Figure 4.3 The impacts of restrictions and constraints to the built-form:

- The early skyscraper setback form.
- The built-forms impact by the FAR, the site setback angle, the solar envelope principles.
- Building Restrictions: The buildable floor area ratio (F.A.R.) development and the setback angle from street.

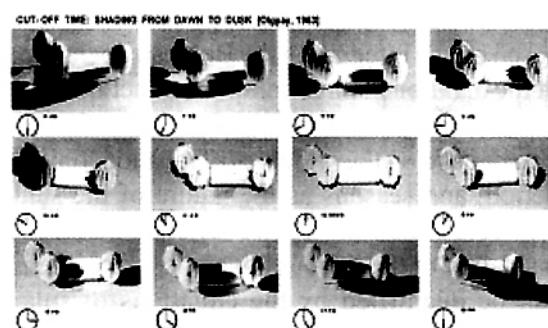


Figure 4.4 Influences of solar radiation and overshadowing to adjacent site during the day.

(C) Solar Envelope Volume:

This component considers the skin-load conditions that rely on an availability of solar energy and the effect of on site shading according to the site conditions. The Solar Envelope configuration is based on Ralph Knowles's minimum shading set on the assumed condition line, "Fence", along with site's perimeter boundary (see Figure 4.5). The Fence condition is created by developing a plotted line of intersection points between on-site shading line and the outer vertical line of Buildable Volume plane along with the boundary. The form of the Solar Envelope can vary according to the solar-site related conditions and sun-shading. Both Solar Envelope and shading principles will allow designer to accurately define the shape, plane, and volume of shading area and non-shading area on the site and Buildable Volume.

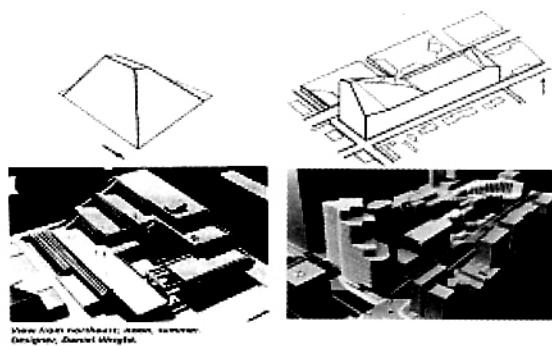
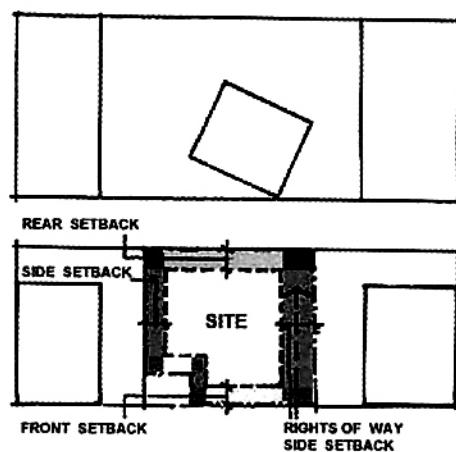


Figure 4.5 Examples of the implementation of the solar envelope principle.

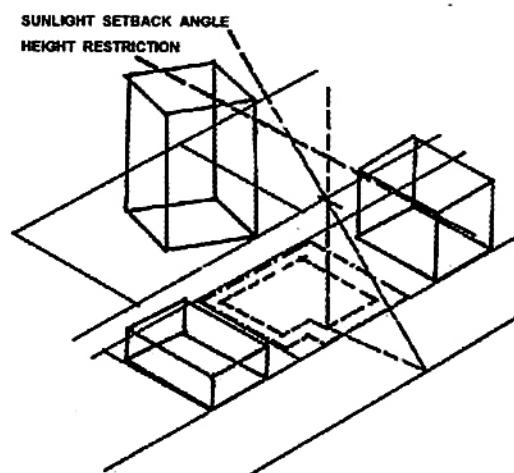
4.3 Methodology

The SEEDA methodology is constructed based on the integration, by Boolean operation, of the mentioned three component factors. The different shape and forms of the three factors also depend on the variables of location, timing period, and seasons as the nature of the sun-site relationship. However, the different insolation of the various envelopes' facet areas can be quantified by the equations of solar geometry, solar engineering principles, and trigonometric calculation. For SEEDA method, first the program will define the Buildable

Volume, Height Restriction, and Site Restriction and Constraints (Setback and Setback Angle). In this research, the US most restrictive building regulations of the important cities, such as New York, Chicago, and San Francisco [City of Chicago, 2002; BOCA, 2000], will be used for the development of SEEDA case studies in order to cover the factors that will influence the physical built form of the design (See Figure 4.6-4.7).



A) SITE SETBACK CONSTRAINTS



B) HEIGHT RESTRICTIONS & STREET SETBACK ANGLE

Figure 4.6 Site restriction and constraints: site setback (a), setback angle (b)

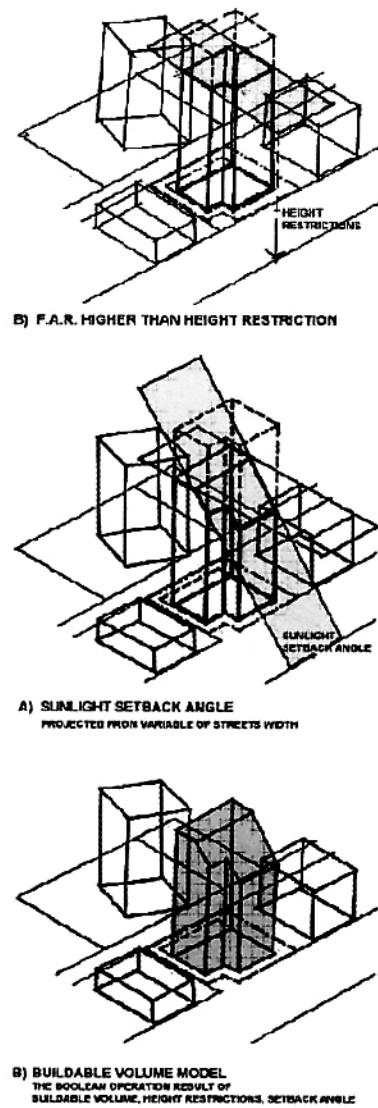


Figure 4.7 Implementing of height restriction, site setback angle restriction in the SEEDA's Method Modeling

Since the sun movement and site conditions can cause significant physical impact on the building design as well as operation, accurately predicting both the potential benefits and the detriments is vital for achieving low-energy architecture design. Therefore, if the architect can define the impact results of the specific solar resources to the proposed site, he/she can define the effective and responsive of solar-site conditions for the design.

The SEEDA' Menu provide the flexibility for the designer to fill in the variations of the

input data for any regional climate site, latitude, and selected time. After entering the data, the solar projection part in SEEDA program will continuously generate the Shading Condition Volumes by projecting the hourly solar radiation through the roof top corners of surrounding buildings and computing their shadows that will cast on the ground level. Two extreme timing, Summer Solstice and Winter Solstice, are the conditions program that will calculate and compare the worst scenario to generate its shadow line (See Figure 4.8).

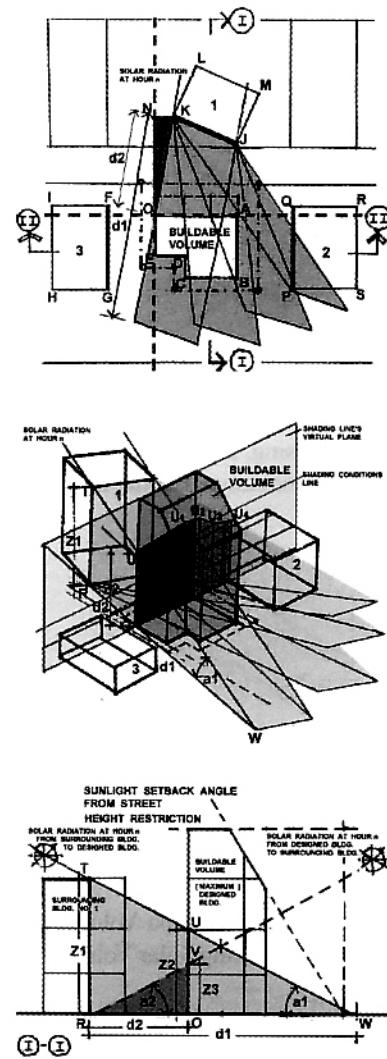
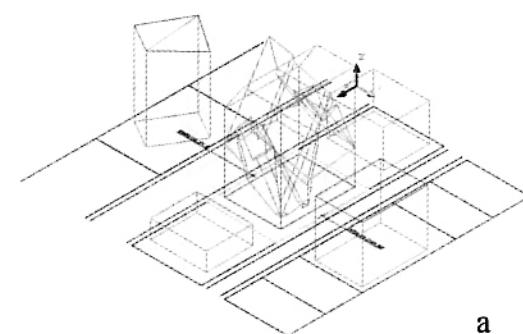
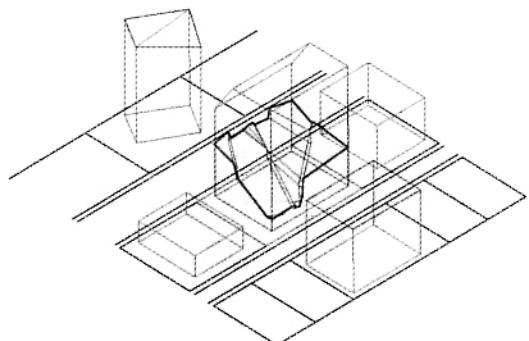
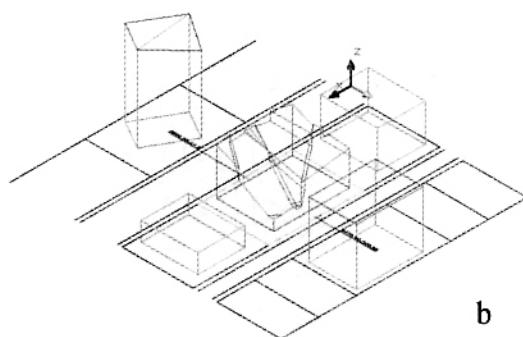


Figure 4.8 Implementing of shadow projecting technique in SEEDA Method

By the AutoLisp written programming and necessary input data filled by the user, SEEDA would generate Buildable Volume and the site's Shading Condition Volumes based on each specific concept as mentioned. SEEDA then performs the Boolean operation and identifies the separated portion of the Shading Solar Volume and Direct Solar Volume superimposing on the same maximum Buildable Volume basis (Figure 4.9). The program would further generate the Solar Envelope Volume above the separated line, Fence Line, of the Shading Solar Volume and Direct Solar Volume (Figure 4.10).



a



b

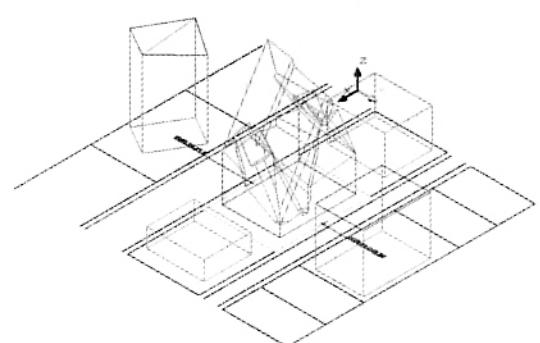
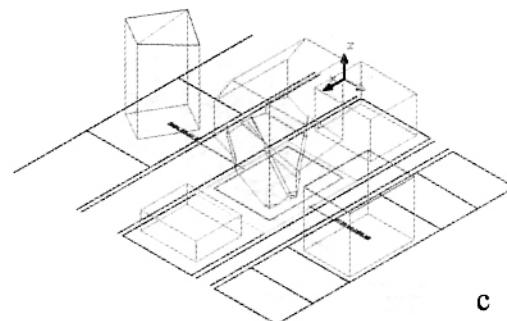


Figure 4.10 The solar Envelope Volume above the Fence Line and the Shading Solar Volume

At the end, the three type volumes; Shading Solar Volume, Direct Solar Volume, and Solar Envelope Volume will be saved for the potential built-form. They represent the maximum available both solar radiation levels and characteristics form for the site (Figure 4.11).

Figure 4.11 The Shading Solar Volume, the Direct Solar Volume, and the Solar Envelope Volume, will be saved for the Potential Built-form Base-Case

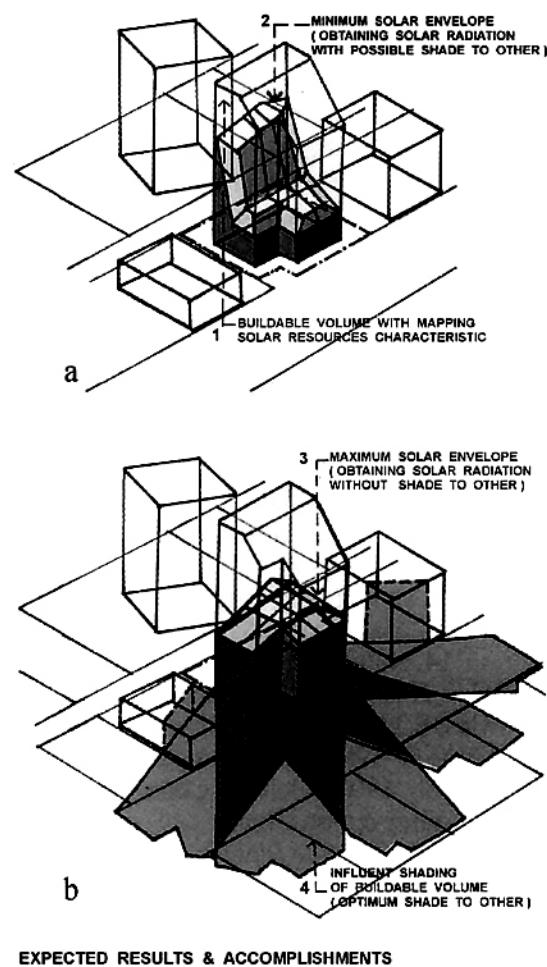
The shapes of the three component models are determined by each specific set of criteria. The first component, Maximum Buildable Volume, is based on the building and zoning restrictions. The second component, the Shading Condition Volumes, is based on combining hourly shading volumes of the surrounding buildings through daily operation hours, for the two extreme scenarios, the Summer Solstice and the Winter Solstice [Duffie and Beckman, 1991]. The third component, Solar Envelope Volume,

is the volume that is set over the parameter of coverage area, "Fence" line as of Ralph Knowles's Solar Envelope principle [Knowles, 1983].

For Knowles's principles, the volume is to be set at the lowest level of the site at ground floor or assumed to set at the average height of a property's top fence which the name "Fence Line" is derived from. For the SEEDA method, the Fence Line is the linking line of the highest hourly overshadowing planes casting by Shading Condition Volumes that is on the Maximum Buildable Volume facets. This is to take the true obstructing shading conditions of the site into account of the solar volume mapping. Therefore, the SEEDA method's Solar Envelope Volume will be generated on the enhanced Fence Line as shown in the Figure 4.9-4.10.

The three SEEDA's component models will be generated as three-dimensional solid entities. This is to allow them to be able to perform the Boolean operations, subtraction, union, and intersection, by the computer aided design routine functions. To obtain the solar characteristic of the designed site, three categories of Boolean operation are programmed to define the three result volumes. These volumes are Solar Shading Volume, Solar Direct Volume, and Solar Envelope Volume which represent the different characteristic of solar conditions available for the site. The Solar Shading Volume is the lower Buildable Volume that will be shaded by surrounding buildings shadow (Shading Condition Volumes) and will respond only diffusion and constant reflected light. The Solar Direct Volume and Solar Envelope Volume are the upper Buildable Volumes above shading area that will respond to direct radiation, or beam radiation, with diffusion and constant reflected light (Figure 4.12 a). After the three types of the solar volumes have been verified, the method of solar radiation, insolation, and computation will be used for the theories and formulae of solar engineering based on the two prominent sources, one is Duffie and Beckman, 1991 and ASHARE, 1995. If any facets of the three volumes are selected, the SEEDA program will compute the insolation of these facets. If any of the three mentioned Solar Volumes are selected for the

shadow projection, the SEEDA program could generate the shading volume using the same part of the program that can generate the Shading Condition Volumes (Figure 4.12 b). In conclusion, designers can use this design methodology to verify the available solar characteristic of the sites and use the information to implement the appropriate design for their projects.



EXPECTED RESULTS & ACCOMPLISHMENTS

Figure 4.12(a) SEEDA method's Solar Shading Volume, Solar Direct Volume, and Solar Envelope Volume,
(b) Possible overshadow projection to the adjacent sites

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