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SIMULATION IN THE BUILDING DESIGN PROCESS

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Abstract- The employment of simulation into the design process brings different advantages to building design. Different reviews were carried out to integrate of the building simulation into the architectural design process. Most of them attempt to find some new ways, similar to the engineer's way of using the simulation. There is an untrue idiom confidence that a good use of building simulation is what engineers do by simulation. So most of the surveys have searched for a kind of process, which render architects able to imitate the engineer's way. But there is an essential difference between the approaches of architects and engineers. However the advantages of application the building simulation by architects in the early design stage is widely authorized in different appraisals, not many architects use these tools during the design process. This raises the question of idiom and clear reasons behind the limited use of simulation. These reasons derive from different sources. There are different obstacle which confine wider application of the tools among design practitioners. To remarkably increase building energy performance, the use of building simulation software at the earliest has been emphasized. Fundamental complexity in data representation, I/O (Input and Output) and apparition of available software requires professional knowledge to leverage the potentials offered. Early stages of design are distinguished by unstructured and insufficient data which is defective as inputs to software based on detailed representations of the systems in the building. Existing simulation software, developed in research organizations are targeted to be used by building services engineers at detailed stages and does not suit the purposes of design community. This article attempts at recognizing the reasons behind unpopularity of simulation software in the early stages of design and also asserts that a new sort of determination support systems is needed for energy efficient building design.

Keywords: Simulation Methods, Building Design, Design Process, Energy.

I. INTRODUCTION

Simulation is assigned with speeding up the design process, increasing efficiency, and allowing the comparison of a broader range of design variants. Simulation provides a better understanding of the results of design decisions, which increases the success of the engineering design process as a whole. But the connection of simulation in the design process is not always recognized by design teams, and if recognized, simulation tools cannot always declare effective answers. This is particularly true in the early design stages as many early research endeavors to embed "simplified" of "designer-friendly" simulation instruments in design environments have not completed their objectives.

For more than a quarter of a century, building performance simulation programs have been expanded to manage non-trivial building analysis and assessments. In general these programs deal only with a small sub- set of the general problem. However, advanced architectural developments require an integrated approach to design.

It is commonly known that many indoor environment and sustainable energy related problems happen in buildings. There is fundamental evidence that one of the major causes is the traditional engineering approach which can be characterized as mono-disciplinary and primarily focused on static design confine conditions while using simplified analytic solution methods. However we now also have computer simulation tools which can be characterized as multi-disciplinary, able to analyze all operating conditions throughout the year and which are based on numerical methods.

The main difference between traditional tools and computer simulation tools is related to the complication of the underlying models. Traditional models have in the order of 10 variables and aim to generate an exact solution of a very simplified model of reality. Simulation models may include more than 10,000 variables. They aim to generate a best possible solution of a sensible model of reality, which should comply with Einstein's principle which states that a model should be as simple as possible but not simpler. Computer simulation involves performing experiments with an implicit model of reality. There is a connection with experiments on physical models which are used for confirmation, establishment and scaling.

II. A BRIEF HISTORY OF SIMULATION

Design tools have traditionally been constructed by diminishing the complexity of the underlying system mathematical problems in an attempt to lessen the computational load and the corresponding input load placed on the user. Some portion of the system may be neglected , time fixed values may be assigned to some system parameters or simple boundary conditions may be inflicted . Within a simulation program such assumptions are defection. Instead, a mathematical model is constructed to display each possible energy flowpath and their interactions. In this sense simulation is an attempt to imitate the reality. The evolution of design tools, from traditional manual methods to contemporary simulators, is summarized in Table 1.

Table 1. Evolution of design tools [2]

Generation	Characteristics	Consequences
1	- handbook oriented - simplified and piecemeal - familiar to practitioners	- easy to use, difficult to translate to real world, non-integrative, - application limited, deficiencies hidden
2	- building dynamics stressed - less simplified, still piecemeal - based on standard theories	
3	- field problem approach - shift to numerical methods - integrated modelling stressed - graphical user interface - partial interoperability enabled	- increasing integrity vis-a-vis the real world
4 and beyond	- good match with reality intelligent knowledge-based - fully integrated - network compatible	- deficiencies overt, - easy to use and interpret, predictive - and multivariate, - ubiquitous and accessible

There is no attempt to constantly represent the energy and mass flowpaths that occur in real buildings. The purpose is only to provide users with an indication of performance:

A 1st generation program is consequently easy to apply but difficult to clarify since the user is required to admire its limitations and make appropriate allotment.

In the mid-'70s 2nd generation programs began to appear. These stressed the temporal facet of the problem, particularly with respect to long time constant elements such as multi-layered constructions. The underlying calculation methods remained analytical and step by step.

With the appearance of more powerful personal computing, 3rd generation programs began to emerged as a viable anticipation in the mid-''80s. These conclude that only the space and time dimensions are independent variables; all other system parameters are dependent so that no single energy transfer process can be solved in isolation. This signalled the beginning of united modelling whereby the thermal, visual and acoustic aspects of performance are considered together [2].

In the mid-'90s, the amplitude integration work continued apace but with the addition of program interoperability, which is essentially a data modelling case. Also, and in response to the growing uptake by practitioners, new developments commenced concerned with knowledge-based user interfaces, application quality control and user training. As summarised in Figure 1, the use of design tools has until now adhered to a tool-box metaphor by which the designer must recognise a particular task, locate a suitable program, apply it and translate its outputs to suitable modifications to the design theory.

This is an unfair model in that the tools are decoupled from the process and require the designer to translate between data models. A more eligible approach is summarised in Figure 2, which shows a computer-supported design environment (CSDE).

The designer develops the design supposition in such a way that the computer applications are able to automatically access the data describing the design and give feedback on all aspects of performance and cost in terms significant to the designer.

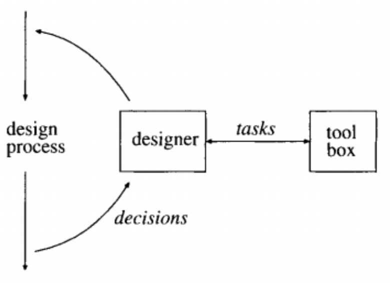

Figure 1. Tool-box approach [2]

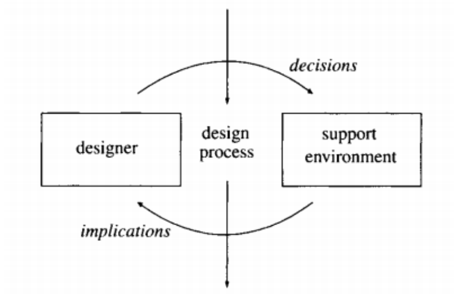

Figure 2. CSDE approach [2]

The access of such a CSDE is a non-trivial task requiring the development of a computational model of the design process in which the role of each contributor, human and otherwise, is clearly defined.

III. SIMULATION OVERVIEW

Consider Figure 3, which shows the flowpaths experienced within and outwith buildings and which interact, in a dynamic manner, to dictate comfort levels and energy demands. To understand the simulation approach, it is useful to evoke such a system as an electrical network of time dependent persistences and capacitances subjected to time dependent potential differences.

The currents to result in each branch of the network are then equipollent to the heat flows between the building's parts. Constructional elements, room contents, glazing systems, plant components, renewable energy devices etc. may be treated as network nodes and characterised by capacitance, with the inter-node connections characterised by direction. Nodes possess variables of state such as temperature and pressure . Since nodes have different capacitances, the problem is essentially dynamic: each node responding at a different rate as it competes with its neighbours to catch, store and release energy.

It is this distributed dynamic behaviour, along with the non-trivial nature of the branch flows and network parameters, that imparts complexity to the building modelling task. The resolution of the model that is the number of nodes a function of the analysis objectives. an early design stage approximation of summertime temperatures will require a lower level of discretisation than a detailed study of indoor air quality.

From a mathematical viewpoint, several complex equation types must be solved to accurately represent such a system and, because these equations demonstrate heat transfer processes that are highly inter-related, it is necessary to apply synchronic solution techniques if the performance prediction is to be both accurate and preserve the spatial and temporal integrity of the modelled system.

It is possible to use simulation at an early design stage to determine the optimum incorporation of zone layout and constructional plan that will provide a climate responsive solution and so minimise the need for mechanical plant. Some simulations might focus on the choice of constructional materials and their relative positioning within multi-layered constructions so that good temperature and load levelling is attained. Also, alternative daylight capture and shading strategies might be investigated to ensure glare avoidance, excess solar gain control and minimum luminaire usage. After a fundamentally sound design has emerged, well tested in terms of its performance under a range of anticipated operating conditions, a number of alternative control frameworks can be simulated.

Further analysis might focus on smart control by which the system is designed to respond to occupancy levels or indoor daylight illuminance. Yet further simulations might be undertaken to ensure acceptable indoor air quality or explore the eventuality of deploying local renewable energy conversion devices such as photovoltaic cells. Its ability to deal with the resulting complexity of scale and diversity of component interactions has obtained building simulation a well-respected role in the prediction, assessment, and confirmation of building behavior. Specialized firms offer these services in any life cycle stage to any stake holder.

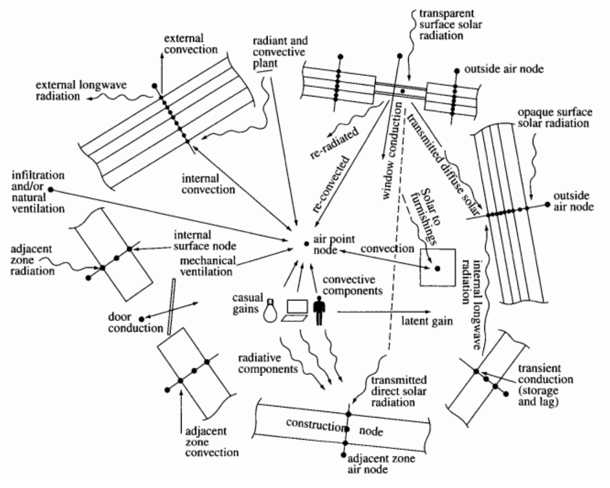

Figure 3. Building energy flowpaths [2]

Figure 4 sketches the evolution of attention in building performance simulation for building design. We are now at the point where it is important to try to raise the realistic level by increasing the usability of this technology for performance based building and systems design [1].

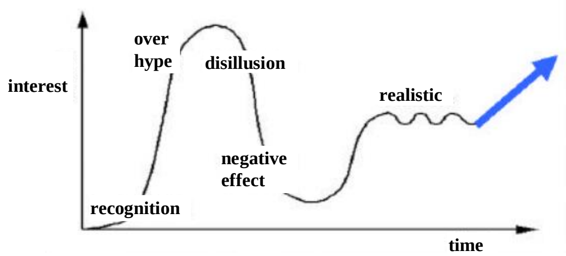

Figure 4. Schematic evolution of interest in building performance simulation [1]

Computer aided building energy simulation falls into two main categories (Figure 5) based on modelling approach: zonal and CFD (Computational Fluid Dynamics). Software based on zonal modelling manner gives statistical indication of year-round energy performance of the building. To reduce intricacy and calculation time, these models are simplified where every point in space/ zone is considered to be in similar thermal state. New calculation engines encircleing new features can be implemented into existing skeleton. Software based on zonal modelling can again be categorized into two: steady-state and dynamic. These tools are limited in abilities to simulate large single space with spatial differences. CFD tools are based on the principles of fluid flow and able to represent real-life situations more exactly than their zonal peers.

3D space is divided into large number of grids and each node in the grid is determined an initial value for different environmental parameters. Based on the equations of mass, momentum and enthalpy protection; assigned values are replaced by solving the equations numerically. Computationally expensive CFD tools require enormous endeavor in preparing mesh and have limited use in building design.

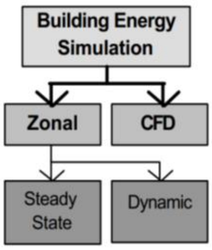

Figure 5. Types of building simulation software

IV. BUILDING SIMULATION METHODS

Simulations to produce multi-view evaluations may be achieved by the application of different methods: stand-alone, interoperable, run-time coupling and integrated. A brief description of each method, as reported by Citherlet (2001), is provided in the following sub-sections.

A. Stand-Alone

This is the most basic approach to produce an united performance view. The applications used are entirely unrelated and therefore different input models must be created for each one. This method is time consuming because of the decoupling, for example geometry changes in one application must be reimplemented in the others to maintain constancy and harmony. Such repeated modifications also increase the possibility of user error because of the inexorable differences between data models and user interfaces. With regards to the investigation, analysis and presentation of simulation data, this method renders the process unwieldy and complicated because there are multiple result sets to be processed, analysed and integrated [3].

B. Interoperable

In this manner, the building model is shared between applications although different interfaces are still used for each application. The main problem with this method is that dynamic data exchange during simulation is not possible; the user must invocate other applications in order to exchange the data model between applications. The method may be further sub-divided as follows.

B.1. Exchange of Building Model

In this method, two or more stand-alone applications may exchange the building model using an unbiased file format. The main advantage of this sub-method is its greater efficiency and lesser required information to create the building model. However, because each application has a unique building model, multiple and distinct models must be updated when the project changes.

B.2. Sharing of Building Model

In this manner, a single building model exists, which is shared by all applications and managed centrally by a data management system. This approach draws its advantage from the existence of a central information appropriateness and conservation point for all applications data. However, to manage parallel access to the same data source is a non-trivial task.

C. Run-Time Coupling

This method allows automatic data exchange during run-time. Usually, there is a prevailing application, which drives the simulation. When this application requires information from another application, it issues a request and the second application is automatically started. The advantage of this method is the automatic exchange of data during the simulation process. However, a drawback still insists: the preservation of data consistency in the context of the separate evolution of applications. In regards to the exploration, analysis and presentation of simulation data, this method is absorbing because the data model is held in a central location while the output data comes merely from the main application.

D. Integrated Method

As the expression indicates, the integrated method brings together the different applications as shown in the schema of Figure 6. The integrated method, like its run-time coupling counterpart, benefits from automatic data exchange during the simulation process with the target of solving a set of combined equations that represent the concurrently occurring physical phenomena. The main advantage of this method is that the building model data is better managed because the evolution of the application does not depend on external simulation engines. The remaining drawback is that the user still needs to understand the different technical domains. In regards to the exploration, analysis and presentation of simulation data, there is no additional development because the data model is also held in one central location and the output data comes solely from one application [3]. Table 2 summarises the possibilities offered by the four itemised approaches to a multiple view assessment of building performance

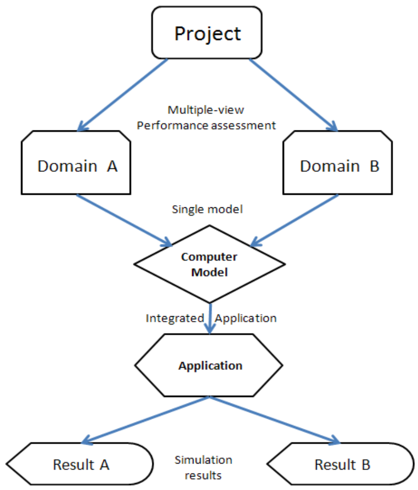

Figure 6. Integrated method [3]

Table 2. Comparison of multiple view assessment methods [3]

Approach	Advantages	Disadvantages
Stand-alone	- Problem specific application	- Several data models - Several user interfaces - No dynamic data exchange
Interoperable	- Single data model - Model consistency	- Several user interfaces - No dynamic data exchange - Transaction management - Complete model if missing data
Run-time coupling	- Single data model - Model consistency - Single user interface - Dynamic data exchange - Physical model	- Link consistency maintenance
Integrated	- Single data model - Single user interface - Dynamic data exchange - Model consistency -Application maintenance	- Require knowledge in various domains

In the author's opinion, only the coupled and the integrated approach can take into account the dynamic behaviour of a building. The efficient development and use of an integrated application requires knowledge of the various views assessed and of positive principles, as well as expertise in computer simulation. But once the physical model has been created, the integrated approach allows a flexible, simple and powerful multiple-view appraisement of building performance.

V. SIMULATION IN THE DESIGN PROCESS

To establish a holistic design approach with simulation having an input at all stages it was necessary to define the design approach of the architecture practice used as a test bed. The approach developed was also compared with related approaches in the published literature.

The RIBA design plan of work identifies three main building design stages:
• Outline Design Stage
• Scheme Design Stage
• Detailed Design Stage

Different design objectives and areas can be observed in the different building design stages. The aim was to distinguish for the different stages key parameters that are part of the designer's consideration, which will have a significant domination on the energy and environmental performance of the building and for this reason which should be included in simulation studies.

The following section covers, for each design stage:
• A short description summarising the RIBA definition of different building design stages.
• Comments on how simulation can provide further design support.
• Key elements required to successfully integrate simulation into the design process.

A. Outline Design Stage

In this design stage a concept based on feasibility studies is prepared. It shows the design analysis and options considered, and will be sufficiently detailed to institute the outline proposal preferred. It can involve diagrammatic analysis of the requirements on the site, solutions to functional and circulation problems, associations of spaces, massing, construction and environmental methods and a cost assessment to enable a resemblance of construction cost. This design stage is extremely time constrained.

B. Scheme Design Stage

The Outline Design Stage proposal approved by the client is now taken to a more detailed level. Sensible material produced can include site layout, planning and spatial arrangements, elevation treatment, construction and environmental systems. Simulation will focus on problem areas or on typical building sections. In terms of environmental simulation this stage can be seen as a load downgrading stage, with the designer having more time available to spend on certain issues.

C. Detailed Design Stage

The approved Scheme Design solution is worked through in detail. Detailed design drawings are produced for proportionate structure, services and specialist assembling. Internal spaces may be detailed to include fittings, equipment and finishes. At this design stage the application of simulation relates mainly to engineering issues and it will be experts using the tool. They will use simulation for purposes such as designing a natural ventilation strategy or to model other building services applications such as chilled construction systems or air conditioning systems.

Inappropriate modelling of the design process may result in ineffective design tools and solutions. In general, there are two main categories of design:
-Architectural design that works on graphical images to determine the architectural form, shape, facade, etc.
-Engineering design that works on system schematics to perform thermal and HVAC calculations.

Architects usually develop their designs in drawing-based, graphical forms; prototypes are used to investigate the design concepts. What is important here is that building design is a creative process based on iteration: it consists of a continuous back-and-forth process as the designer selects from a universe of available components and controls options to synthesize the solution within given constraints. Figure 7 displays tasks that have to be accomplished during a simulation exercise [4].

Building design often happens in a unorganized fashion and frequently jumps from concept to concept. Energy design is only one consideration amongst many and often not as important and distinguished as the others. Since energy performance has usually been invisible, the most that could be hoped for in the past was that the architect would follow some general guidelines for energy efficiency and make sure the design fell within certain constraints. Since architectural design decisions have a remarkable impact on building energy performance, it is favorable to improve this area by an efficient simulation environment.

To solve a design problem using simulation, care should be taken to consider, inter alia, the nature of the problem and the approach of the consideration. Explicit knowledge on how to translate the problem into proper input and how to use tool for evaluation is currently lacking.

Integration of simulation into the building design process can verify that important data and information for each major design decision is provided in a timely fashion. By establishing design links and exchange between architecture and engineering, an integrated building design system can be developed.

With the development of computer-aided design, building energy simulation and analysis is an important element in an integrated building design methodology. Program development for future simulation tools consists of some of the following features:
• Fully integrated and interactive.
• Graphical user interface to streamline the data and knowledge transfer.
• Link with computer-aided design & drafting tools.
• Data transfer between various building design software tools.
• Development of database and standard for building products.

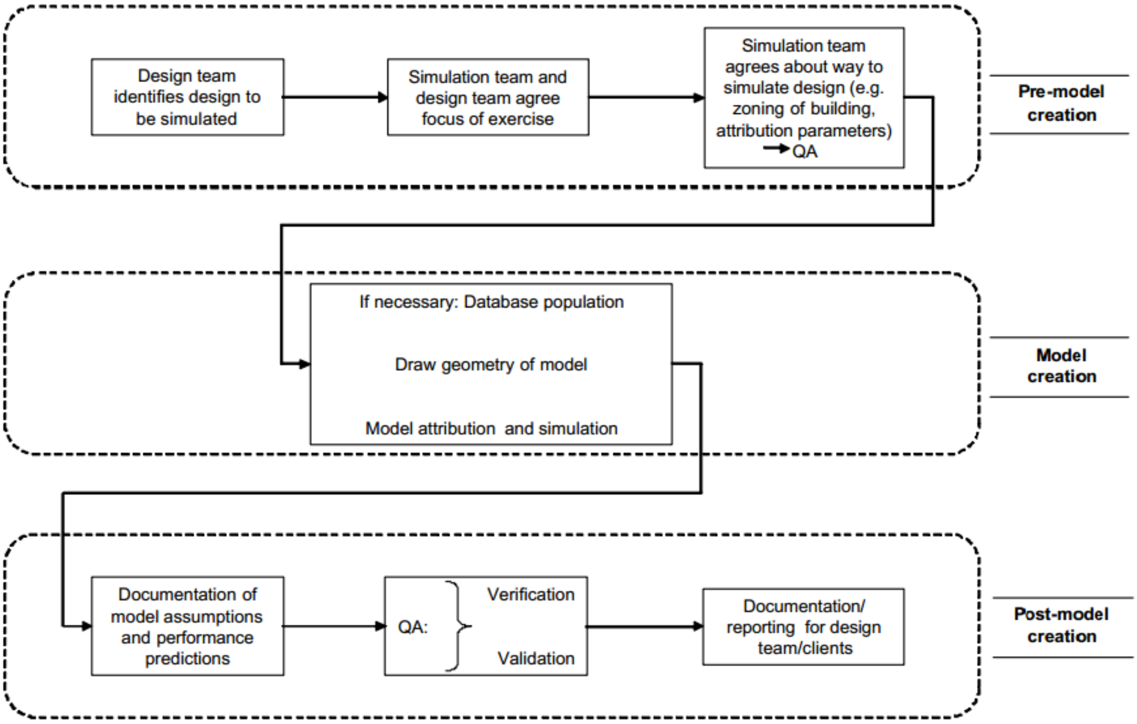

Figure 7. The process of creating and simulating a model [4]

VI. CONCLUSIONS

As computer simulation tools are persistently changing and evolving, it is useful at this time to outline the current and future development of building energy simulation. Knowledge about the properties, applications and limitations of simulation tools is of practical importance because both current and potential users of the tools are, to some extent, obstruct and confused by the existing programs. To apply simulation tools and techniques successfully, a clear understanding of the building design process and its relationship with the simulation environment is recommendable since humans (in other words architects) and not computers dictate the creative and evaluation process.

Building simulation is currently not an integrated element of the design process. However, because of the complexity of the design process and the advanced technologies now applied in the building industry this would be very desirable. Integrating modelling would raise awareness of energy and environmental issues and give it an adequate status in design decision making.

Different design objectives and scopes can be perceived in the different building design stages. Research was undertaken to identify for each design stage key parameters pertaining to energy and environmental performance that could be addressed by simulation. The concept developed is based on the use of one simulation program throughout the design process to ensure continuity between the different design stages. Effective results presentation is a key element of the use of building simulation software. For this reason the results analysis should again be customised to the different design stages. Detailed information can be confusing for occasional users but vital for the expert user.

With a better understanding of building energy simulation through education and training, it is possible for us to establish confidence and efficiency in the use of simulation based design tools.

REFERENCES

[1] J.L.M. Hensen, "Notes on Building Performance Simulation and the Role of IBPSA", 11th Brazilian Congress of Thermal Sciences and Engineering, Brazili, pp. 1075-1081, 2006.
[2] J. Clarke, "Energy Simulation in Building Design", 2nd Edition, Butterworth and Heineman, Oxford, pp. 4-7, 2001.
[3] S. Citherlet, "Towards the Holistic Assessment of Building Performance Based on an Integrated Model Approach", Ph.D. Thesis, Swiss Federal Institute of Technology, Switzerland, pp. 16-22, 2001.
[4] Ch.A. Morbitzer, "Towards the Integration of Simulation into the Building Design Process", Ph.D. Thesis, Department of Mechanical Engineering, Energy System Research Unit, University of Strathclyde, Glasgow, UK, 2003.
[5] B. Ahmadkhani Maleki, "Traditional Sustainable Solutions in Iranian Desert Architecture to Solve the Energy Problem", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 6, Vol. 3, No. 1, pp. 84-91, March 2011.
[6] B. Ahmadkhani Maleki, "Wind Catcher: Passive and Low Energy Cooling System in Iranian Vernacular Architecture", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 8, Vol. 8, No. 3, pp. 84-91, September 2011.

BIOGRAPHIES

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