DESIGN INFORMATICS

Navigating Dynamic Knowledge **Flows In** Discontinuous **Innovation** Enterprises


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ABSTRACT

This paper presents the emergence of *design informatics* where the fields of business management and computer science merge to support profitable sustainable innovation processes. The paper chronicles the journey to find solutions to mitigate costly knowledge losses during complex product innovation processes, the recent successes and the future of this emerging field by the Environmental Design Integration Research Group at the Faculty of Design and Architecture, Universiti Putra Malaysia. The paper describes knowledge loss as the inability of continuous progressive flow of any necessary working knowledge for completing a task during a product's innovation lifecycle process. These knowledge losses keep recurring thus causing unnecessary delays and costing significant losses to their respective enterprises. The author's doctoral dissertation found the problematic sources in four operating environmental characteristics for such complex enterprises—*1) having multiple sequential and concurrent workflows, 2) having discontinuous memberships in the organization overseeing each different workflow, 3) having multiple interdependent tasks between multiple workflows, and 4) having tacit regression in their working knowledge-dominant areas.* Founded on these four characteristics, the author has advanced design research investigations into understanding the product development processes for successful IT/ICT integration and understanding stakeholders' behaviour and cognition for successful collaborations. Furthermore, her investigations have expanded to understand and streamline people and processes that utilize different knowledge types and sustainable resources for successful product innovations. With reference to completed dissertations she had supervised, the author discusses the types of knowledge contributions, the dominant research methodologies conducted, and the trans-disciplinary supervisory involved. The paper concludes with explanation how these findings become the foundation for the field *of Design Informatics* at Universiti Putra Malaysia. The paper recommends on how the new field can support the Economic Transformation Programme for Malaysia in the future.

Keywords: Design, Design Informatics, Discontinuous Enterprises, Dynamic Knowledge Flows, Sustainable Product Innovations, Integrated Design

INTRODUCTION

Unnecessary rework, delay, and lost revenue are synonyms in the construction industry. In one hotel development project, the owner had to replace all the 550 fire doors to his hotel's rooms because the doors were oversized by several centimetres. The doors were pre-ordered and specially made several months before their installation. In the same hotel project, all the crystal chandeliers imported from a Scandinavian country could not fit into their concrete nestings. Hence, they were hung 60 cm lower than its original installation height which made the ballroom much lower and lacks its intended grandiose. Such missed coordination of information continues to recur to this date even when a property development organization has explicit information or maintains one project manager throughout the property development process. These missed coordinations undermine Cohen and Levinthal's (1990) absorptive capacity theory that an organization's knowledge is built upon its prior knowledge because somehow that knowledge is missing from the organization.

The fire doors costed more than RM350,000 to be replaced because they would compromise their fire resistance if the edges were shaved to fit into their framed openings. The expensive chandelier sets were ordered more than two years prior to their fitting in their respective concrete nests. Obviously, the missing information in the two cases are 1) a door needs its framing system in the wall opening and 2) the concrete nesting requires cement plaster finish to cover the rough concrete base before its final dimensions. In both incidences, the interior fittings were ordered according to the openings in the rough concrete base. The door frame and the cement plaster finish were "missed" during the interactions between the owner, the architect, the interior designer, the main contractor, and the interior design subcontractor. The aboveare two of the author's personal examples exemplifying the "horror stories" in the property development industry. They motivated her to investigate the phenomenon of discontinuous membership and the associated knowledge-flow interactions. The huge pile of documents was not helpful in pinpointing the culprit as everyone was simply doing his tasks in his workflow process. The intent was to mitigate the high cost and delay in the construction industry and find solutions to streamline the design-manufacturing-construction process per se.

THE KNOWLEDGE LOSS PHENOMENON

The author defines knowledge loss as the inability of continuous progressive downstream flow of any necessary working knowledge for completing a task during a product's innovation lifecycle process. These knowledge losses keep recurring and causing unnecessary delays and costing significant losses to the enterprises. An enterprise comprises of several organizations required to complete a complex workflow where each organization has a set of personnel and a process to produce an artefact (Ibrahim, 2005). The key was then, to find the source of this recurring menace. Knowledge loss (K-loss) matters when it impacts a project's or product's schedule and cost. The doctoral work by the author (Ibrahim, 2005) followed Nonaka (1994) in defining *knowledge* as a set of commitments and beliefs of its bearer that enable him or her to undertake certain action. Thus, the criterion in using the term 'knowledge' in this paper is its *enabling action* entity that allows the bearer of a knowledge entity to undertake certain action. *Explicit knowledge* is the selected and applicable group of facts that is transmittable in a formal systematic language that *enables* its bearer to take some action to complete a task; and *tacit knowledge* is the entity of "knowing how" that an individual or an enterprise possesses in selecting and applying a group of facts that *enables* action to complete a task. Ibrahim (2005) defines *information* as the selective collection group of facts that an agent *can use* to perform a task, while *data* are facts that an individual or enterprise *can use* to analyse or make a decision.

Emerging information can complicate the already complex process, extend the delivery schedule, or increase the cost so much that it is no longer worth pursuing. It is important to reduce the number of abandoned development projects because the economy of a country may be at stake. Hence, the initial study was motivated by the need to facilitate the transfer of tacit knowledge among members of a property development team with *discontinuous memberships*. According to Ibrahim (2005), discontinuous membership is an organizational operating situation where team members can join the organization to perform their specific roles and leave when they have completed them while the workflow progresses. This term was earlier used by Anderson and Tushman (1990) to describe the 'break' that happened when technology advancement would force previous technology to discontinue hence forcing organizational change. In the author's context, Ibrahim (2005) describes the term as *the discontinuity of an organizational structure caused by the change in skill set requirements for handling tasks in different lifecycle phases.*

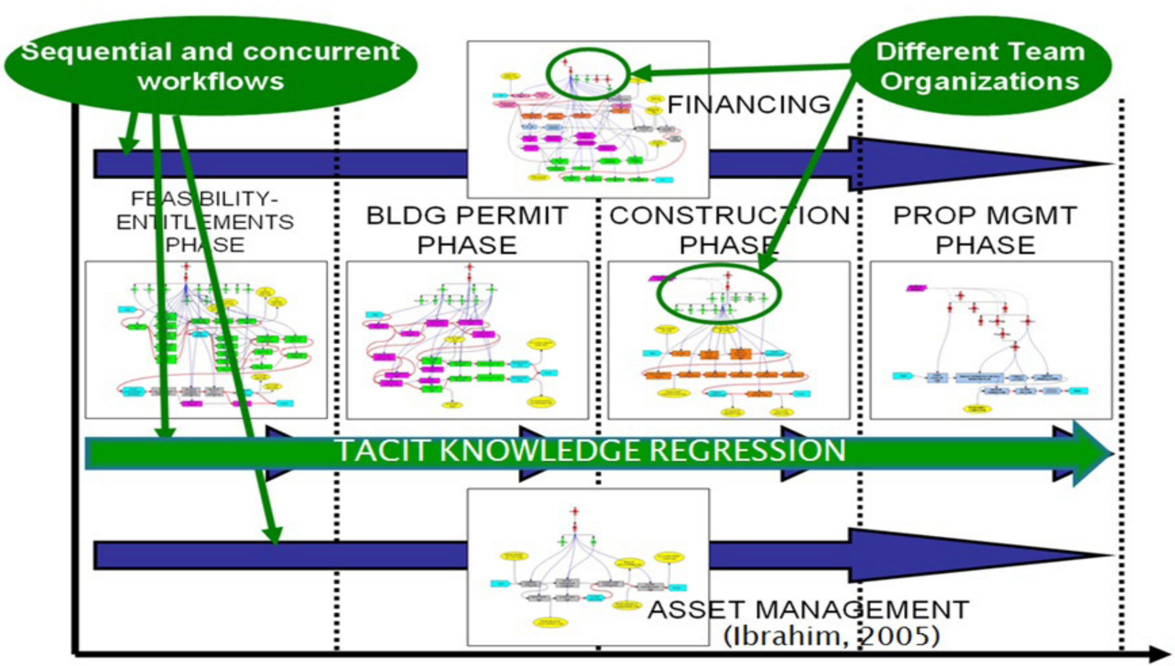
The author's doctoral main research goal and challenge was to develop a flexible knowledge management system that captures both the tacit and explicit knowledge during a property development lifecycle process and could be employed in the complex property development process. In order to create a suitable knowledge management system for the organization, the study had to understand the type of organization the system will support and the form of information the stakeholders need for the property development process. By the end of the author's second year at Stanford University, she realized the gigantic challenges she faced: 1) working in the tacit realm (a knowledge claim nightmare) and

2) working in the knowledge transfer phase (the most challenging phase in knowledge management field). By the end of the author's third year, there was no knowledge management system in view and then, came the time to take stock of the dissertation progress. It was a turnaround time for the author because progress was unsatisfactory. The reason was, how one could develop a solution when she did not know the source causing the knowledge loss phenomenon in the construction industry!

SOURCES FOR KNOWLEDGE LOSSES

The author's doctoral thesis (Ibrahim, 2005) found four operating environmental characteristics—*multiple concurrent and sequential phases, discontinuous memberships, tasks interdependencies* and *different dominating knowledge types for each lifecycle phases*—contributing to the knowledge-loss phenomenon in a complex product development process. The doctoral study conducted a mixed-method case study research on a non-profit housing developer whose housing projects all received grants from the American government. This section describes those four operating environmental characteristics below which would become the foundation for the design and development of future IT/ICT-integrated sustainable product innovation lifecycle processes. Figure 1 illustrates where these characteristics occur in a property development process.

Figure 1 Multiple concurrent and sequential phases, discontinuous memberships, tasks interdependencies and different dominating knowledge types for each lifecyclephases within a property development process (Source: Ibrahim, 2005)



Ibrahim & Paulson (2008) reported the development of the above-mentioned characteristics for the property development industry that could explain how knowledge flows impact organizational performance. The first construct is having multiple concurrent and sequential phases. Their ethnographic study found the feasibility-entitlements, building permit, construction and property management phases to occur in a sequential order while it found finance and asset management to be concurrent with the sequential phases. The second is having discontinuous memberships. This is a unique organizational character where Ibrahim & Paulson (2008) had documented a dynamic management structure that varies across different property development lifecycle phases.

The third construct is task interdependencies where several tasks in the sequential phases are interdependent with other tasks in the concurrent phases. Referring to Figure 2, the ending and starting of a lifecycle phase form the major convergent points for concurrent workflows during the property development lifecycle process. Due to the high number of interdependencies, Ibrahim & Paulson found critical paths would readjust naturally due to any delay in obtaining the relevant approvals, failure to obtain the applied financing, addition of tasks and rework of completed tasks.

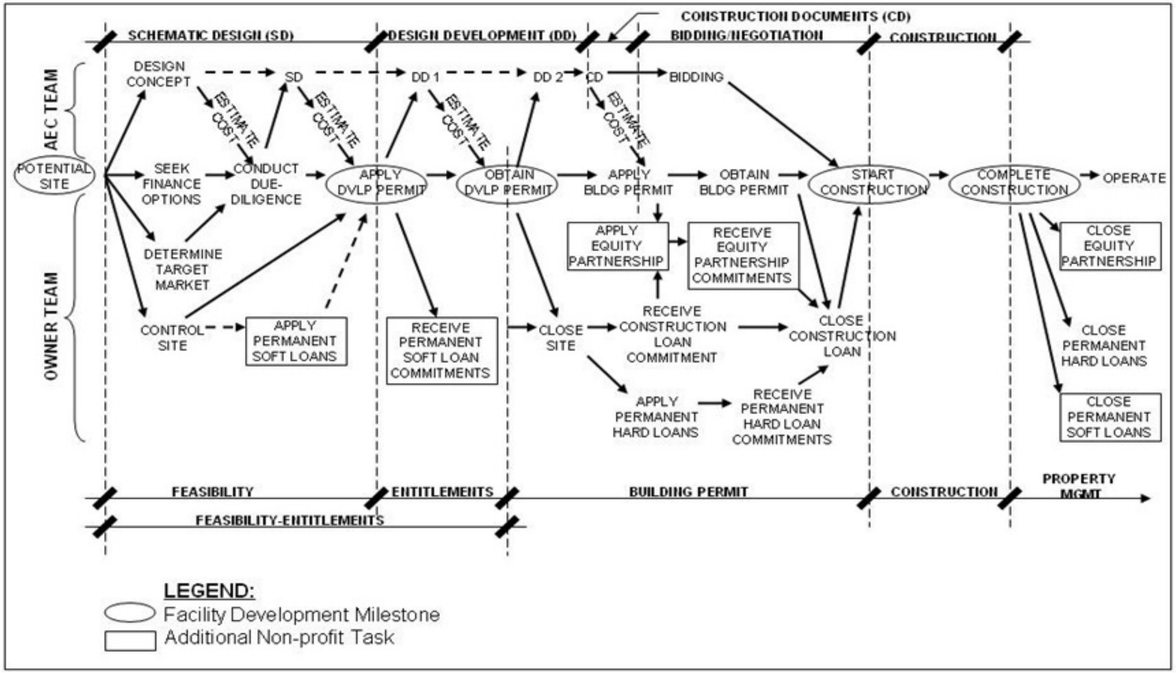
The fourth construct is each workflow has different knowledge type. Ibrahim & Paulson's (2008) ethnography study documented two types of knowledge dominating during different property development lifecycle phases. Specifically, tacit knowledge dominates during the early feasibility and entitlements phase, while explicit knowledge is increasingly dominant as the development project progresses. Their study found that the project managers are highly skilled at obtaining tacit knowledge by socializing and internalizing the actions and sayings of the local elected officials and the public that support them.

Table 1 Discontinuous Memberships during Different Lifecycle Phases in a Property Development Process (Source: Ibrahim & Paulson (2008), Table 1)

Agent's Position Phase	FE	BP	CO	PM	DPF	AM
OWNER						
Executive Director	0.40	0.20	0.20	0.20	0.20	0.20
Project Manager	0.50	0.20	0.20	0.20	0.25	0.15
Services Director				0.10	0.10	
Accounting Department					0.50	
Chief Operating Officer				0.30		
Public Relations Exec.				1.00		
Regional Manager				0.30		
Compliance Specialist				1.00		
Property Manager				0.30		
Site Manager				1.00		
A-E CONSULTANTS & BUILDER						
Title Company	1.00					
Environmental Engineer	1.00					
Surveyor	1.00		1.00			
Architect	1.00	4.00	0.50			
Civil Engineer	0.50	1.00	0.10			
Landscape Architect	0.50	1.00	0.10			
Geotech Engineer	1.00					
Financial Consultant	1.00				1.00	1.00
General Contractor	0.10	1.00	2.00			
Value Engineer	1.00	1.00				
Wood Structural Engineer		0.25	0.10			
Concrete Structural Engineer		0.25	0.10			
MEP Engineer		0.50	0.10			
3rd Party Inspector			0.10			
Geotech Inspector			0.10			
Legal Advisor					0.50	0.15
Auditor					1.00	
TOTAL MEMBERSHIPS PER PHASE						
Total Memberships	12	10	12	9	7	4

Note: FE = Feasibility-Entitlements; BP = Building Permit; CO = Construction; PM = Property Management; DPF = Development
Project Finance; AM = Asset Management; 1FTE = 8-hour per day.

Figure 2 Multiple interdependent tasks existing in a property development process (Source: Ibrahim & Paulson (2008), Figure 1).



They are also equally skilful in ensuring the movement of explicit knowledge among the team members during the design and financing application processes.

The detailed explanation by Shumate, Ibrahim & Levitt (2009) highlights the need for different skill sets requirement which the property development team needs in order to complete the tasks for a particular workflow. The irony of the situation is that the continuous member of the project team—no matter the professional background—is of highly importance to the subsequent project team's organization since the person is the knowledge carrier from the precedinglifecycle phase. In a paper by Ibrahim & Nissen (2007), they explained how this organizational and workflows complexity when combined—and if not well coordinated—could cause unexpected costly project errors when everyone on the project team thought they were doing their best within their individual capacities.

The complex workflows characterized by having multiple interdependent tasks would further aggravate the knowledge movements in the product development lifecycle when knowledge areas for performing the tasks are tacit regressive in nature. Shumate, Ibrahim & Levitt (2009) found that during the earlier phases of a product innovation process, project team members are working at higher tacit knowledge level. These experts are usually senior project managers who are able to manoeuvre socially, politically, and financially during the complex property development process. However, whenever the project team's organizational composition changes in the subsequent lifecycle phases, their tacit knowledge may leave with the discontinued members when their services are no longer required. Thus, their discontinuity would affect the organizational performance of that enterprise.

In the discussion following the findings of these four characteristics, Ibrahim & Nissen (2007) question the validity of Burton's & Obel's (1998) Contingency Factor and "proposed a new contingency factor called *Knowledge* with *tacit* and *explicit knowledge* as its values." Both scholars also questioned Galbraith's (1974) information processing theory in business operations since it cannot fully support the operations of highly discontinuous teams identified by Ibrahim (2005) and described by Ibrahim & Paulson (2008). Ibrahim (2005) then proposed the possibility of another organizational character which informed us the existence of a horizontal peer-to-peer knowledge movement together with Galbraith's (1974) single and vertical (or hierarchical) knowledge movement. The computational simulation by Ibrahim (2005) and Ibrahim, Levitt & Ramsey (2005) validates this theoretical proposition.

OPPORTUNITIES IN MANAGING INTERDEPENDENCIES

The challenge to improve a product lifecycle management was to find one project that could become the base for developing and testing these new theoretical findings. The Institute of Tropical Forest and Forest Products (INTROP) provided an opportunity when the author became an Associate Researcher and initiated the timber industrialized building systems (IBS) programme with support from the Malaysian Timber Industries Board (MTIB).

Ibrahim (2009) described the under laying principles behind the sustainable product lifecycle management specifically for the timber industrialised building systems (IBS) programme. Figure 3 illustrates how an integrated design management approach is critical to oversee the farming of resources used in the construction industry, the integrated design-manufacturing processes, and the eventual assembly of the timber IBS components on a project's site. Supporting the timber IBS programme are works that include 3D design integration, 3D e-submission, 4D construction to 3D property management. The content for the building information modelling process are provided by the Malaysian industry standards for energy efficiency and building by-laws with supporting 3D IBS components database. Encouraged by the dearth of studies in the design field, the author had so far focused on design-related issues in building information modelling for sustainable building lifecycle. Among the areas of interests are modular coordination or IBS design process, building components, manufacturing, delivery and assembly, IT-integrated facility management, IT-integrated tools and methodologies and multi-disciplinary collaboration. Additionally, it also extends to improve commercialization of IBS products especially those related to green materials and technologies. In the following section, the author explains how recent completed efforts by several graduate students at the Faculty of Design and Architecture are supporting this vision.

Figure 3 The importance of integrated design management in managing renewable resources, manufacturing and implementation of industrialized timber construction in the field of Design Informatics.

UNDERSTANDING DISCONTINUOUS DYNAMICITY

The earlier findings by Ibrahim (2005) have been further enhanced by continuing researches conducted at Universiti Putra Malaysia with graduate students in the fields of Architectural and Integrated Design Studies. Their dissertations attempt to resolve problems related to the existence of interdependent tasks and could be divided into 1) understanding product lifecycle processes for successful IT/ICT integration; 2) understanding the stakeholders for successful product delivery; 3) understanding product knowledge and resources as foundation to sustainable innovations; and 4) streamlining people and processes for successful integrated product delivery. The author elaborates below how their studies contributed to expanding the depth and breadth of understanding and mitigating the effects of dynamic knowledge flows and discontinuous organizations.

Understanding Product Lifecycle Processes for Successful IT/ICT Integration

There is never a doubt about the increasing ubiquitous applications based on IT/ICT-supported processes in global practices. The author believes in introducing IT/ICT in workflow processes without causing the process recipient undue stress; and to succeed it becomes more important to understand the local processes before a new technology is introduced. In this light, several studies have looked into understanding and improving the intuitive design process for later integration with IT/ICT while several studies have looked into integrating or introducing successful technology or system into the present project delivery management.

In the first study, visualizing the link between human behavioural needs with spatial needs are often difficult for novice architects during the initial architectural conceptual design phase.

Ali GhaffarianHosseini (2008) introduces Social Network Analysis (SNA)—commonly used in the communications field to study relationships between people—for solving this visualization problem. The research intent was to affirm whether or not SNA could be utilized as a spatial planning tool during conceptual building design. GhaffarianHosseini posited that since the nodes and structural relationships between the nodes may have similar architectural characteristics, the tool would enable architects to make changes by moving any spaces on a floor plan while safely maintaining their spatial relationships to other spaces. He developed a proof-of-concept prototype to facilitate spatial diagramming visualization during conceptual design phase. The prototype proved successful in handling the necessary complexity in the spatial diagramming exercises caused by multi-layered spatial arrangements at the horizontal and vertical planes.

A study by Farzad PourRahimian (2009) aimed to optimize the level of cognition and collaboration during conceptual architectural design phase by novice designers when they need to employ more flexible and intuitive digital media. He studied the feasibility of using VR 3D sketching interface in order to replace the non-intuitive Computer Aided Design (CAD) tools. By understanding the knowledge flow characteristics among mentors and apprentices in real-life architectural conception in studio projects, the study found current conventional CAD tools do hinder novice designers' creativity due to their limitation in intuitive ideation. The case study's findings then became the theoretical foundations for the development of a VR 3D sketching interface for enhancing novice designers' cognition and collaboration during the conceptual design process.

The intuitive nature of early design stage, specifically the conceptual design stage, has similar challenges amongst the industrial designers. Azrol Kassim (2011) introduces virtual prototyping tools at a new level where he studied their feasibility in selecting materials during an industrial design practice. His study documented the current limitation of tools which were less intuitive to support an industrial designer's creative approach during material evaluation. Results of his study suggested feasible characteristics of VP tools to support industrial design practice in addition to providing a guideline to improve the tool's cognitive and intuitive support to its intended user.

Norshahrene Mohammad (2012) formalized BES (Building Environmental Simulation) during the Schematic Design Phase for the Public Works Department of Malaysia. The traditional BES involved complex and highly technical calculation and architects were not encouraged to crosscheck their designs unless necessary. Her study documented existing BES barriers besides determining the functional performance and requirements in architectural design and design workflow process of that organization. The enhanced architectural design practice guidelines are expected to make BES more acceptable by the Public Works Department's architects to predict building performance in term of energy use and environmental and sustainable practices during early schematic design phase.

At the manufacturing stage, Golnar Kiani (2012) would like to facilitate the production of non-linear dynamic forms of building designs where current prearranged machines and moulding systems still draw a lot of limitations to architects. She focused on means of rapid manufacturing which are more advanced in other industries where she had identified adoptable process stages and evaluating their criteria to be adopted into the construction industry. She had also analysed the *kenaf* bio-composite material specification and composition for the system and process that could take place using

Selective Laser Sintering technology. In so doing, she contributed in developing an integrated approach to predict *kenaf* hybrid composites for non-linear constructional components.

Mohd Zairul Mohd Nor (2012) and Ahmad Tholhath (2012) focused on improving integrated project delivery. Mohd Zairul Mohd Nor (2012) found nine Concurrent Engineering (CE) principles which can be adopted in the mass housing industry due to its similarity in nature with its counterpart in the manufacturing sector. They would satisfy housing delivery quality and competitiveness. On the other hand, Ahmad Tholhath (2012) studied the feasibility of introducing BIM (Building Information Modelling) coordination in order to improve sustainable development of resort projects in the Maldives. His study found 11 conditions for achieving sustainability through coordination and integration by BIM that could increase quality and productivity while decreasing cost and duration in Maldives.

Understanding Stakeholders for Successful Product Development

A product cannot be developed successfully if it does not fulfil the need of the very users it is intended for. Studies to understand indigenous culture and especially in regards to application and adaptation of high technologies are still lacking. The following describes two studies in this regard.

In the first study, globalization has changed the design collaboration activity which requires participation of multipleprofessionals to accomplish an agreed design task over dispersed geographical location through the Internet or an intranet server. Naeimeh Delaveri (2012) highlighted a working-culture deficiency with regards to IT-supported technologies in the design collaboration process. Her study aimed to find a way how one could engage Malaysian professional architects in IT-integrated collaborations and to improve their interaction with computing systems using the concept of Human Computer Interaction (HCI). She developed an IT-engagement model to increase architects' motivation to collaborate using collaborative technologies. Upon identifying current collaborative technologies and how design team members could use them, she used the existing parameters of engagement from theories of technology adoption and studies of IT-integrated design collaboration to establish feedback, control and functionality as the criteria for developing a model of engagement for design team members using IT-supported technology.

In another spectrum, Shahab Abbaszadeh (2009) studied the needs of reinforcing social interaction among Persian neighbourhood communities in new high-rise residential development. His study found neighbourhood communities losing their social interactions when residences were stacked into high-rise residential buildings complexes in Mashhad metropolis, Iran. He established that social interaction among residents will occur successfully when a complex of several high-rise residential buildings provides secured, supportive, collective, and responsive spaces for them. Additionally, he also established high-rise residential district as a neighbourhood community consisting of several high-rise residential buildings which encourages social interactions through well-integrated *secured, supportive, collective and responsive spaces.* He contributed in future development of high-rise living being more supportive of the socio-cultural well-being of the intended residents.

Understanding Product Knowledge and Resources as Foundation to Sustainable Innovations

More studies on understanding product knowledge and resources are needed for designers in creating competitive products. Zohreh Pourzolfaghar (2011) focused on capturing tacit knowledge in facilitating knowledge flows during a product development process. The tacit regressive nature of the product development process requires a project manager to be more diligent in ensuring appropriate and accurate knowledge would pass on to the succeeding task in such a dynamic lifecycle. Her study developed a technique to capture mechanical/electrical knowledge that could match and support the architectural conceptual design activities. The same technique could be extended to other knowledge fields throughout different lifecycle phases of a building project.

Both Mohd Fadhil Ahmad (expected 2013) and Rosalam Che Me (2013) studied *kenaf* as alternative product material specifically for rapid prototyping and for artificial limbs respectively. Mohd Fadhil Ahmad (expected 2013) proposed a new formulation to reduce the cost of material for 3D printing system by incorporating the local and renewable source in the like of *kenaf*-core natural fibre. On the other hand, Rosalam Che Me (2013) wove *kenaf* fibre to form layers of laminated composite as replacement for glass fibres in the production of prosthetic leg socket. The layered *kenaf* bio-composite is intended to replace the Glass Fibre Reinforced Plastic (GRFP) commonly used in prosthetic leg.

Financing is one of the integral components in property development. Bardia Bakhtiar (2009) developed an alternative solution for housing developers in Malaysia who cannot rely on government subsidies to build affordable quality housings for the whole nation. The financial model considers selected elements for

Smart Growth which is expected to assist low-income families to build their lives and enable them to save enough money to buy their own homes eventually.

Streamlining People and Processes for Successful Integrated Product Delivery

In this section, the author presents how the merging of people and process knowledge can improve integrated product delivery processes. The author explains how people and process integrations have been successfully developed for use during conceptual design, design development and fabrication phases in a building lifecycle. For Malaysia, the Construction Industry Master Plan (CIMP 2005-2015) outlined the focus in utilizing industrialized building system (IBS)—an exclusive construction method that deals with prefabricated building components (known in Malaysia as IBS Components) followed by on-site installation. The following studies highlight several achievements to improve integrated product delivery processes at various stages of a building lifecycle.

In the conceptual design phase, Ali GhaffarianHoseini (2013) further extended his earlier work (Ali GhaffarianHoseini, 2009) to improve the procedure of automatically evaluating the functional efficiency of architectural plan layouts. The Rapid Spatial Planning System (Ibrahim, Abdullah & GhaffarianHoseini, 2008) is a step forward towards automation of the architectural spatial diagramming. He extended VDT's organizational design simulation/evaluation theory (Jin & Levitt, 1996) for building design process. Hence, his work advances the formalization of graph theoretical principles of Social Network Analysis in architectural conceptual design applications.

Maziyar Mamdooh (2013) finds the IBS method effective when it harmonises and manages IBS components in a modular and repetitive manner called Modular Design Process (MDP). While the IBS method is supported and requested firmly by the Malaysian Government in public projects, the IBS Survey 2005 (Construction Industry Development Board, 2005) revealed that many Malaysian architects were still unwilling to incorporate either IBS or MDP in their common practices. To improve the interaction between architects and industrialized components' fabricators, Maziyar Mamdooh (2013) developed the IBS Interface System (Ibrahim, Abdullah, Jaafar & Mamdooh, 2011) with exclusive functionality in aggregating and distributing the IBS digital component information through a classified naming system in order for facilitating modular design process in BIM. Eventually, his research claims four contribution areas of knowledge: 1) converting architects' demands into tool functionalities; 2) prioritising the IBS Component Information based on architects' perspective; 3) generating the CCN for enumeration and retention of 3D Prefabricated Building Components; and 4) developing a new design framework for 3D MDP. The results of his study are expected to intensify the use of IBS components among local architects in line with the national agenda of Malaysian construction industry.

In the implementation phase, Siva Jaganathan's (2011)study led to the development of an integrated system design model for industrialized building in timber and the development of the spacer architectonic building system (Ibrahim & Jaganathan, 2009). His study argued for current building systems to have form flexibility facilitating fluid architectural design. He found the fragmented process of design, manufacturing and assembling physical building elements and components of the prefabrication processes limiting design flexibility to their availability in limited industrialized components. The integrated system design model actually merges the design development and detailed design/construction documentation phases of the architectural design lifecycle thereby shortening the duration of the design phase while reducing redundant design flaws commonly occurring during the manufacturing/production and assembly-able construction.

DISCUSSIONS AND FUTURE DIRECTION

In this paper, the author has divided progresses in understanding and mitigating the discontinuous dynamicity in knowledge flows in the building lifecycle into four areas. Completed works in understanding product lifecycle processes for successful IT/ICT integration involved identification of design parameters or design knowledge components besides documentation of design techniques and workflow processes in different types of product development projects. Completed works in understanding the stakeholders for successful product delivery so far involved the dynamicity of collaborative work amongst the designers and users' behavioural preferences for cultural preservation. Completed works in understanding product knowledge and resources as foundation to sustainable innovations so far include capturing different knowledge types in the product itself, improvement to material applications and financing components for affordable housing development. Completed works for streamlining people and processes for successful integrated product delivery so far has developed novel systems during different product development lifecycle based on BIM and IBS construction. Herewith, the author presents three aspects in product development research evidenced by the above-mentioned studies: type of knowledge contributions, dominant design research methodologies used, and trans-disciplinary supervisory involvements. Then, the author discusses how these findings would formulate the foundation for establishing *design informatics*for the future.

Types of Knowledge Contribution

A large portion of completed works in design research which the author exemplified above contribute new theories which were proven and validated either through enhanced proof-of-concept prototypes or product/process models. The author divides the major knowledge contribution outputs from the above-mentioned studies into three categories of knowledge contributions: enhanced processes, enhanced products and novel integrated systems (See Table 2). The enhanced process category covers process that is enhanced through people's cognitive improvement (such as Naeimeh Delaveri (2012), Farzad PourRahimian (2009) and Azrol Kassim (2011)). Another area of enhanced process covers process that is enhanced through people's behavioural changes (such as Mohd. Zairul Mohd. Noor (2012) and Norshahrene Mohammad (2012)). The final area covers the enhanced actual product development process (such as Ali Ghaffarian (2008), Ahmed Tholhath (expected 2013) and Golnar Kiani (2012)).

Table 2 Distribution of New Knowledge Contributions in Design Informatics Researches

NO	THESIS TITLE	INQUIRY STRATEGY	THEORY	ENHANCED PRODUCT	ENHANCED PROCESS	NOVEL SYSTEM
	DOCTORAL LEVEL					
1	**Bardia Bakhtiar. 2009.** “Development of smart growth Islamic financing model for building affordable quality housing in metropolitan areas.”	Case Study	X	X		
2	**Farzad Pour Rahimian Leilabadi. 2009.** “Development of 3D sketching concept in VR for expediting digitization during integrated design process.”	Mixed-Method	X		X	
3	**Shahab Abbaszadeh.** 2009. “Maintaining Persian social interaction in high-rise buildings in Iran.”	Mixed-Method	X	X		
4	**Zohreh Pourzolfaghar. 2011.“**Improving capturing tacit knowledge during multi-disciplinary design stage.”	Case Study	X	X		
5	**Norshahrene Mohammad. 2012.** “Integrating BES during building information modeling of the conceptual design phase of Public Works Department’s projects.”	Case Study	X		X	

6	**Golnar Kiani. 2012.** "Developing kenaf biocomposites jointing system for architectural design flexbility."	Case Study	X		X	Potential Patent
7	**Naeimah Delaveri.** 2012. "Engaging building professionals in IT/ICT design collaboration for global projects."	Grounded Theory	X		X	
8	**Ali Ghaffarian Hoseini. 2012.** "Automating the evaluation of architectural layout efficiency."	Mixed-Method	X	X	X	Patent
9	**Maziyar Mamdooh. 2013.** "Development of an IBS Interface System for Facilitating 3d Modular Design Process in Malaysia."	Mixed-Method	X	X	X	Patent
	MASTERS LEVEL					
10	**Ali Ghaffarian Hoseini. 2008.** "Adapting social network analysis for visualizing spatial planning during conceptual design phase."	Experiment			X	
11	**Siva Jaganathan**. **2011.** "Integrated design for enhancing design aesthetics in industrialized projects."	Ethnography	X	X	X	Patent

12	**Azrol Kassim. 2011.** "Utilizing virtual prototyping in material selection for industrial design practice."	Experiment			X	
13	**Mohd. Zairul Mohd. Noor. 2012. "**Feasibility of concurrent engineering in mass housing for Malaysian practice."	Case Study			X	
14	**Rosalam Bin Che Me. 2013.** "Feasibility of kenaf for prosthesis."	Experiment		X		Potential Patent
15	**Mohd. Fadhil Ahmad.** Expected 2013. "Feasibility study on using kenaf for 3D ink jet printing technique in rapid prototyping."	Experiment		X		Potential Patent
16	**Ahmed Tholhath.** Expected 2013. Developing modular sustainable buildings by utilizing BIM for coordination during construction in Maldives.	Case Study			X	

The second category is the enhanced product category. It is defined as improvements to any part or parts of components related to a product, its materials or resources of making, knowledge types involved, etc. In the building aspect, the output by Shahab Abbaszadeh (2009) is about the social interaction in high-rise residential buildings while the output by Zohreh Pourzolfaghar (2011) is about categorization of sustainable mechanical/electrical building knowledge. In the actual product aspect, actual product making are involved. Rosalam Che Me (2013) and Mohd Fadhil Ahmad (expected 2013) contributed in developing cheaper *kenaf*-based products in the form of prosthesis for amputated limbs and powder for 3D printer respectively. Another contribution is Bardia Bakhtiar (2009) which is a financial model for smart growth affordable housing.

The final ultimate category is the actualization of an innovative novel system prototype when an enhanced product is symbiotically integrated with an enhanced process. Ali GhaffarianHoseini (2012) developed a proof-of-concept prototype called Rapid Spatial Planner (RASPER; Ibrahim, Abdullah & GhaffarianHoseini, 2008) for automatically evaluating the functional efficiency of architectural plan layouts. Maziyar Mamdooh (2013) developed another proof-of-concept prototype called IBS Interface System (IBS Interface; Ibrahim, Abdullah, Jaafar & Mamdooh, 2011) for facilitating modular design process based on the modular design process in BIM. Siva Jaganathan (2011) developed an integrated design-fabrication-assembly system for construction using timber called the Spacer Architectonic Building System (SABSystem; Ibrahim & Jaganathan, 2009). All the three integrated systems have been filed for patents in Malaysia and in the process of country filing internationally. While theoretical development is important to enhance the process or product itself—as evidenced herewith for innovating novel knowledge contributions at doctoral level—the author would like to posit that the key to having highly commercialized prototype development is when the enhanced product merged with its enhanced process in a design research inquiry.

Design Research Methodology

There are difficulties in conducting design research and they are mainly caused by limited access to the selected unit of analysis by their researchers. Many researches involved subjective and constructive approaches towards the unit of analysis which caused researchers to employ qualitative research inquiries where case study research methodology is dominant. Among the main reasons are the fact that there are not many building projects to conduct research on, and most property developers do not like risking neither their multi-million projects nor willing to allow experiments conducted on their on-going projects. At the Masters level, Mohd Zairul Mohd Noor (2012) and Ahmed Tholhath (expected 2013) are two such works while at doctoral level are Norshahrene Mohammad (2012), Zohreh Pourzolfaghar (2011) and Bardia Bakhtiar (2009).

Moreover, the author had noticed increasing mixed-method research methodologies within the case study research methodologies employed by graduate candidates especially at doctoral studies. In these cases, the case study research methodologies involved quantitative inquiries to validate the theoretical propositions developed in preceding qualitative inquiries. The case study by Shahab Abbaszadeh (2009) involved extensive survey at a selected large housing project while several case studies included experiments to designer respondents such as by Farzad PourRahimian (2009) and to selected processes by Golnar Kiani (2012). More complex mixed-method studies encompassed computational experiments involving proof-of-concepts prototypical systems developed from preceding qualitative in-depth interviews and observations such as by Maziyar Mamdooh (2013) and Ali GhaffarianHoseini (2013). On the other hand, a single ethnography study by Siva Jaganathan (2011) was able to produce equally high quality patentable innovation when his results could enhance product understanding which was combined with its enhanced process to create a systemic industrialized building system using timber.

The author noted that at Masters level, single inquiry strategy is dominant among Masters candidates. A number of experiments were utilized in testing enhanced process models or proof-of-concept products where the enhanced instruments of inquiry would become the validated models or prototypes of that design research. Among these studies are Ali GhaffarianHoseini (2008), Azrol Kassim (2011), Rosalam Che Me (2013), and Mohd Fadhil Ahmad (expected 2013). In one unique study, Naeimeh Delaware (2012) reverted to grounded theory research methodology to understand the tacit behaviour of architects to engage in IT/ICT design collaboration.

Trans-disciplinary Supervisory

Trans-disciplinary researches, such as those described above, require a composition of multi-disciplinary experts to supervise such a study. Among experts who have contributed their expertise as co-supervisors or co-researchers include researchers from the Faculty of Engineering, the Faculty of Computer Science and Information Technology, the Faculty of Modern Languages and Communication, the Faculty of Human Ecology, and the Institute of Tropical Forest and Forest Products. Trans-disciplinary supervisory requires each supervisor to respect his or her peer expert contribution because he or she may be the sole expert contributor to a dissertation's development. Comparatively, mono-disciplinary dissertation allows its co-supervisors to countercheck each other's expert contribution respectively. The author found a number of graduate candidates who would refrain taking the trans-disciplinary route because of the hardships experienced by the earlier alumni during their viva examinations. While the author found most foreign external examiners quite open and having more experience in examining trans-disciplinary researches, the challenge for the university in general and the faculty especially is seeking internal examiners who could transcend his or her own field to examine a dissertation which aims to make meta-knowledge contributions. In this respect, the author is pleased to note the additional requirement for governmental research grants wanting multi-disciplinary researchers coming together in one research application. The author noted similar positive reaction by Universiti Putra Malaysia to encourage faculties other than research institutes to participate in multi-disciplinary if not in trans-disciplinary research projects.

Future Direction- *Design Informatics*

Ibrahim (2005) found four operating environmental characteristics in complex product innovation enterprises—*1) having multiple sequential and concurrent workflows, 2) having discontinuous memberships in the organization overseeing each different workflow, 3) having multiple interdependent tasks between multiple workflows, and 4) having tacit regression in those working knowledge-dominant areas*. Ibrahim (2005) claims that since complex enterprises will always maintain the discontinuous operational approachfor maximizing profitability, the best recommended solution is to improve the situation where expected interdependencies would occur in those complex workflows. Since 2005, many researches were conducted at the Faculty of Design and Architecture, Universiti Putra Malaysia to understand the necessary ingredients forming the creation of a product thus formalizing the critical knowledge needed in such complex product innovation process. The formalized knowledge will help simplify the workflows thus reducing the interdependencies in them. Later on, improved skills of the stakeholders involved would provide them the capability to perform in those complex discontinuous workflows.

The completed researches at Universiti Putra Malaysia had so far focused on the resources for improving the innovative products and the processes that form their necessary workflows for the respective business organizations producing them. For the design researchesabove, trans-disciplinary approaches have allowed greater meta-knowledge development where researchers boldly venture to enhance the workflows by integrating certain intervention and supporting the product development lifecycle with IT/ICT. Fusing enhanced product's knowledge and resources with enhanced processes has shown great promises for three successful interventions namely *SABSystem* (Ibrahim & Jaganathan, 2009); *RASPER* (Ibrahim, Abdullah & GhaffarianHoseini, 2008); and *IBS Interface* (Ibrahim, Abdullah, Jaafar & Mamdooh, 2012).

The author is pleased to put on record that *SABSystem* had won the Best New Innovation Award for Construction Technology at GreenBuild Asia 2012 while *RASPER* had won a Gold Medal at the British Invention Show 2009. In 2012, *SABSsytem* was licenced to Golden Precision Technologies (M) Sdn. Bhd. which had envisioned its operation as distinct as a start-up operation of a new technology company in Silicon Valley. With strategic business planning, the company is targeting for public listing within five years of its operation. *IBS Interface* is the next innovation ready for commercialization up-scaling and the researchers are making efforts to seek potential investors.

The successes of the three systemic business innovations have further boosted the support for the establishment of *Design Informatics* where the fields of business management (people-process-product) and computer science merge to support profitable sustainable innovation processes. The Environmental Design Integration Research Group at the Faculty of Design and Architecture now has evidences to support the potential of this people-process-product innovation lifecycle in yielding higher commercialization opportunities. The synergy between enhanced product with enhanced process is starting to materialize exciting novel sustainable products thus creating a new playing field for the future. A new playing field is described by Friedman (2006) as the highest level of creative sustenance in future business endeavours. The author called this emerging niche field as *Design Informatics.*

In support of the Economic Transformation Programme for Malaysia (see http://etp.pemandu.gov.my), it was a very rational move to make *Design Informatics* as the underlying foundation in the Transformation Vision Strategy (Ibrahim 2011 & 2012) for the design fields at Universiti Putra Malaysia. Since faculty supports sustainable development, it further creates a focus for*Sustainable Design Informatics*—now a discipline under the university's "Sustainable Human Settlement" and "Environmental Management and Sustainable Development" research programmes.

Sustainable Design Informatics is described as *a design discipline combining design concepts and practices with information technology (IT)—or informatics—for achieving sustainable living* (Ibrahim & Meor Razali, 2012). Ibrahim & Meor Razali explain that it *focuses on the arts and sciences of design relating to collection, creation, storage, retrieval, processing, display and dissemination of knowledge throughout the designed product development lifecycle impacted by information technology.* Furthermore, it is a *trans-*

disciplinary field in design which emphasizes on the development lifecycle of innovative solutions using indigenous resources while addressing socio-cultural needs that meet economical aims. Among its *research targets would include content, methods, technologies and systems besides development of tools, techniques and applications specific and practical for cradle-to-cradle product innovation in certain context.*

CONCLUSION

Establishing the *Design Informatics* niche to mitigate discontinuous membership in high technology complex business enterprises is the start for exciting future systemic innovations for Malaysia and the world. It paves a strategic approach to overcome knowledge losses due to the irrevocable discontinuous operating environment in an already complex product innovation lifecycle which we all can expect to continue growing more complex each day. So long as internet remains in future business environment, the author posits that *Design Informatics* can provide that additional competitive edge when most others will remain ubiquitous for the masses. The author also believes that it will one day become the referral basis for enterprises involve in daily innovations for the betterment of the society while sustaining its resources and environment. In conclusion, *Design Informatics* is one alternative solution for surviving in Friedman's (2006) flat world and it will be an exciting continuous journey for many design researchers already embracing and beholding the competitive entrepreneurial future.

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BIOGRAPHY

Rahinah Ibrahim is an acknowledged scientist in design R&D when the Academy of Sciences Malaysia recognized and awarded her as one of the pioneer Top Research Scientists Malaysia (TRSM) 2012. Ibrahim was the first Ministry of Science, Technology and Innovation's HRD Fund Scholar who obtained a doctoral degree from the School of Engineering, Stanford University in 2005. Born in 1965 in Bentong, Pahang, she graduated with a B.A. in Architecture from University of Washington, Seattle in 1987 and a Master of Architecture from the Southern Institute of Architecture, Los Angeles in 1990. She later, she obtained her Engineer Degree in 2002 and Ph.D. in 2005 in Construction Engineering and Management at Stanford University.

Ibrahim's research on Design Informatics focuses on developing theories and emerging computer-integrated applications for enhancing knowledge flows in sustainable integrated product development lifecycle. In the last 5 years, Ibrahim is the Principal Investigator for more than RM2.2 million research grants. One of the projects includes the development of the Timber Industrialized Building Systems (IBS) Design Guide book for the Malaysian Timber Industries Board to promote the use of timber building in the construction industry. She was awarded RM2.0 million for pre-commercialization of her SABSystem timber framing system in the proposed Green Village project at the UPM Serdang Campus.

Ibrahim is the winner of several international design and research awards. Since 2005, Ibrahim has published more than 180 articles; is lead inventor for 3 inventions which had filed more than 15 IPRs worldwide. One of the inventions has been commercialized for local and international distribution. Ibrahim has graduated 9 Ph.D. and 6 Master students during the same period. She is proud to be the only recipient coming from a design-based research organization for the Top Research Scientists Malaysia 2012.

Rahinah Ibrahim is a Professor in Architecture and current Dean of the Faculty of Design and Architecture, Universiti Putra Malaysia. Ibrahim joined UPM in 1997 after seven years of stint in property development and architecture practice. She led the establishment of UPM's Architecture Programme from 1997 to 2000. She has been appointed as international scientific members and committees to several international conferences. While she was the Deputy Dean (Research, Innovation and Graduate Studies) she had worked closely with university's management team in inculcating research and publication among her design colleagues.

Rahinah Ibrahim had nurtured and managed a total of RM2.8 million new research grants, 31 new project leaders, and registered more than 100 graduate students. These achievements were supported by the establishment of three highly reputable design journal—Alam Cipta, STEdex and the UPM's Virtual Library Museum Pages—which she is one of their founding Editors-in-chief. As Dean since July 2011, she is leading the transformation vision for the Faculty of Design and Architecture towards establishing a strong Design School for UPM focusing on innovation and entrepreneurship.

Ibrahim is very active in NGO works. Her professional affiliations include the Institute of Value Management Malaysia (IVMM) as a Council Member. She is a trustee for Action Caring Team (M) Berhad involving in humanitarian and community development work locally and internationally. For her hospital volunteerism work at Stanford Hospital, Rahinah Ibrahim was a proud recipient of the "Certificate of Special Congressional Recognition in Recognition of Outstanding and Invaluable Service to the Community" by Congresswoman Anna Eshoo, member of the U.S. House Representatives in 2004.

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My gratitude for the late Professor Boyd C. Paulson, Jr. for showing me that affordable housing research is so rich if only we can look beyond the humbleness of affordable housing itself.

I pray for His Patience and Rewards to all my graduated, current and future students for their courage in believing the unknown and venturing into uncharted knowledge territories.

I pray for strength and endeavours to all the design researchers and professionals for making this world a beautiful and sustainable place for our future generations.

I pray for His Rewards to my parents whenever anyone uses and benefits from the knowledge I help created for I do not exist without them.

I pray for His Blessings in faith, health, love and virtue in my large family for knowledge continues showering us the prosperity and richness of living in peace.

Lastly, I pray for His Paradise for my significant other, Datu Mustafa Kamal Mohd Zaini, for being the backbone of my success in this life and hereafter. May He always make us both steadfast to be His catalyst for change.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   Changing Roles of Agricultural Economics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   The Changing Demand for Livestock Products
   20 April 1994

8. Prof. Dr. Ruth Kiew
   Plant Taxonomy, Biodiversity and Conservation
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st Century
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10. Prof. Dr. Shamsuddin Jusop
    Rock, Mineral and Soil
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
Natural Toxicants Affecting Animal Health and Production
29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
Pest Control: A Challenge in Applied Ecology
9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
Managing Challenges in Fisheries Development through Science and Technology
23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
Sejarah Keagungan Bahasa Melayu
6 Ogos 1994

15. Prof. Dr. Law Ah Theem
Oil Pollution in the Malaysian Seas
24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
Fine Chemicals from Biological Resources: The Wealth from Nature
21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
Health, Disease and Death in Creatures Great and Small
25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
Fish Health: An Odyssey through the Asia - Pacific Region
25 March 1995

19. Prof. Dr. Tengku Azmi Tengku Ibrahim
Chromosome Distribution and Production Performance of Water Buffaloes
6 May 1995

20. Prof. Dr. Abdul Hamid Mahmood
Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan
10 Jun 1995

21. Prof. Dr. Rahim Md. Sail
Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
22 July 1995

22. Prof. Dr. Nik Muhammad Nik Abd. Majid
The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
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23. Prof. Dr. Ang Kok Jee
The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century
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24. Prof. Dr. Sharifuddin Haji Abdul Hamid
Management of Highly Weathered Acid Soils for Sustainable Crop Production
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25. Prof. Dr. Yu Swee Yean
Fish Processing and Preservation: Recent Advances and Future Directions
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26. Prof. Dr. Rosli Mohamad
Pesticide Usage: Concern and Options
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27. Prof. Dr. Mohamed Ismail Abdul Karim
Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia
2 March 1996

28. Prof. Dr. Wan Sulaiman Wan Harun
Soil Physics: From Glass Beads to Precision Agriculture
16 March 1996

29. Prof. Dr. Abdul Aziz Abdul Rahman
Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
13 April 1996

30. Prof. Dr. Chew Tek Ann
Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms
27 April 1996

31. Prof. Dr. Mohd. Yusuf Sulaiman
Back to the Future with the Sun
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32. Prof. Dr. Abu Bakar Salleh
Enzyme Technology: The Basis for Biotechnological Development
8 June 1996

33. Prof. Dr. Kamel Ariffin Mohd. Atan
The Fascinating Numbers
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34. Prof. Dr. Ho Yin Wan
Fungi: Friends or Foes
27 July 1996

35. Prof. Dr. Tan Soon Guan
Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too
10 August 1996

36. Prof. Dr. Nazaruddin Mohd. Jali
Will Rural Sociology Remain Relevant in the 21st Century?
21 September 1996

37. Prof. Dr. Abdul Rani Bahaman
Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases
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Market Relationships in the Malaysian Fish Trade: Theory and Application
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Food and Its Healing Power
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Advancing the Fruit Industry in Malaysia: A Need to Shift Research Emphasis
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43. Prof. Dr. Aini Ideris
Avian Respiratory and Immunosuppressive Diseases- A Fatal Attraction
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The Endomycorrhiza: A Futile Investment?
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Molecular Plant Virology: The Way Forward
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47. Prof. Dr. Muhamad Awang
Do We Have Enough Clean Air to Breathe?
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48. Prof. Dr. Lee Chnoong Kheng
Green Environment, Clean Power
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49. Prof. Dr. Mohd. Ghazali Mohayidin
Managing Change in the Agriculture Sector: The Need for Innovative Educational Initiatives
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50. Prof. Dr. Fatimah Mohd. Arshad
Analisis Pemasaran Pertanian di Malaysia: Keperluan Agenda Pembaharuan
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51. Prof. Dr. Nik Mustapha R. Abdullah
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Food Safety: Perspectives and Challenges
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58. Prof. Dr. Ahmad Zubaidi Baharumshah
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62. Prof. Ir. Dr. Radin Umar Radin Sohadi
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64. Prof. Dr. Han Chun Kwong
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65. Prof. Dr. Mawardi Rahmani
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Psychotheraphy for Rural Malays - Does it Work?
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Respiratory Tract Infection: Establishment and Control
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Cocoa-Wonders for Chocolate Lovers
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The Spider Mite Saga: Quest for Biorational Management Strategies
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76. Prof. Datin Dr. Sharifah Md. Nor
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77. Prof. Dr. Ir. Wan Ishak Wan Ismail
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Insect Diseases: Resources for Biopesticide Development
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