The aim of the study is to develop a 'design tool', that is a method to enhance the design and planning of facilities for the sustainable production of new knowledge. The tool is focused on the necessary spatial conditions pertaining to this end, especially the topological networks.

One condition contributing significantly to sustainably producing of new knowledge is knowledge '*diversity'* of people interacting within what have been called '*cluster*s'. Facilities for sustainably producing new knowledge have to combine the advantages of both virtual and physical means. In certain situations, over-reliance on virtual media may to lead to 'Cyberbalkanization'. This study thus concentrates on enhancing interaction in the 'real places' that exist in built environments.

To provide a better understanding of the concepts of diversity and cluster formation related to the physical spatial organization of a facility, the campus of TU Delft was chosen as a case study. The study shows that the possibility for physical interaction between knowledge agents in clusters from diverse academic backgrounds is very low, which forces us to think about conditions that may increase them. As a result, the study is concerned with the necessary conditions to allow the formation of clusters of high diversity in knowledge production facilities. These conditions are represented in terms of topological networks consisting of nodes, which represent places for potential encounters, and links between nodes, which represent accessibility between such places. We use the term '*Archigraph*' for these networks.

To construct the design tool, three examples of applications are considered to explore how the tool can be constructed. The three examples illustrate how to compare diversity of interacting groups in clusters for schemes in three different situations as follows: different network structure but similar allocation; different allocation but the same network structure; and different allocation with different network structure.

To test the tool, two design options from a real design competition are used in another case study. We compare the 'diversity index' of the schemes using the design tool. Possible modifications to the tool are suggested as a result of this case study.

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1. The transfer of *concepts and techniques* from the domains of economics, regional science, environmental sustainability, and sociology to the domain of spatial design, on the scale of building complexes;
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The design tool proposed here is not intended for use as a deterministic design machine but as an aid to providing a better understanding in comparing alternative building plans when the topological network is taken as a necessary condition for enhancing physical interaction among diverse agents.

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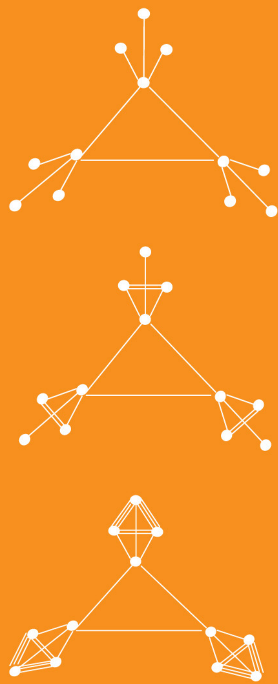
A Tool for the Design of Facilities for the Sustainable Production of Knowledge   Jun WU

A TOOL FOR THE DESIGN OF FACILITIES FOR THE SUSTAINABLE PRODUCTION OF KNOWLEDGE



Jun WU

A Tool for the Design of Facilities for the Sustainable Production of Knowledge

A Tool for the Design of Facilities for the Sustainable Production of Knowledge

Proefschrift

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door

Jun WU

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Rector Magnificus	Voorzitter
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To my parents, my sister and Huanhuan

ABSTRACT

The aim of the study is to develop a 'design tool', that is a method to enhance the design and planning of facilities for the sustainable production of new knowledge. More precisely, the objective is to identify a method to support the conception of building complexes related to the long-term production of new knowledge. The tool is focused on the necessary spatial conditions pertaining to this end, especially the topological networks.

Today, with profound developments in what has been called the *Knowledge Economy* and consequent changes in our society, new challenging design problems have to be faced. It appears that one of the most crucial of these is to design *Sustainable Innovation Facilities* which can meet the new needs and exploit the potential of the *New Environment* of our time. To solve this new problem, a new set of design methods is needed, in the form of a design tool.

The concept of '*Sustainable Development*' in the economy and the environment is applied to the production of new knowledge. The basic feature of 'Sustainable Development' is generalized as: the process of increasing or at least maintaining output in a changing environment by means of adaptation. One condition contributing significantly to such adaptation is knowledge '*diversity'* of people interacting within what have been called '*cluster*s'. There are two possibilities of achieving such clusters of high diversity: 1) through 'virtual' media and 2) through face-to-face interaction in 'real' places. Both are seen to be of value. Hence, facilities for sustainably producing new knowledge have to combine the advantages of both virtual and physical means. In certain situations, over-reliance on virtual media may to lead to 'Cyberbalkanization'. This study thus concentrates on enhancing interaction in the 'real places' that exist in built environments.

To measure physical diversity in clusters, three steps are suggested:

1. The identification of clustering locations in innovation facilities;
2. The identification of users interacting in such clustering locations;
3. The measurement of the diversity of the agents interacting in such clusters.

To provide a better understanding of the concepts of diversity and cluster formation related to the physical spatial organization of a facility, the campus of TU Delft was chosen as a case study. The study shows that the possibility for physical interaction between knowledge agents in clusters from diverse academic backgrounds is very low, which forces us to think about conditions that may increase them. As a result, the study is concerned with the necessary conditions to allow the formation of clusters of high diversity in knowledge production

facilities. These conditions are represented in terms of topological networks consisting of nodes, which represent places for potential encounters, and links between nodes, which represent accessibility between such places. We use the term '*Archigraph*' for these networks.

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The design tool proposed here is not intended for use as a deterministic design machine but as an aid to providing a better understanding in comparing alternative building plans when the topological network is taken as a necessary condition for enhancing physical interaction among diverse agents.

Keywords:

Sustainable Innovation Facilities

Necessary Design Conditions

Diversity in Clusters

Archigraph

Design Methodology

Design Tool Development

Preface and Acknowledgements

Architecture is to me a journey from disorder to order. On the journey, I have wondered: What are the models which can represent such order in Architecture and Urban Design in a changing world? What is the role which 'diversity' plays in design projects enhancing the sustainable environment, economy and society? Nowadays the architectural and urban researches in China are still too poor to face multitudinous problems emerging from the booming environment, economy and society. I believe that the steady progress can be achieved if we seriously study more diverse thoughts, more scientific methodologies and more innovative insights from the outside.

Beyond the discussion of diversity in Architecture and Urban Design, Chinese civilization was once a pioneer in the world, due to its openness to the diverse world outside, but later its influence declined, probably due to *the Great Wall both on the landscape and in the minds*, which gradually blocked the path of diverse information and thinking entering from the outside. Although openness might invite invaders and destroyers, it does provide such a chance to adapt to the changing world. Now comes China's chance to revive, in the epoch of the 'Knowledge Economy' in which 'diversity' plays an important role in promoting 'sustainable innovation'. The need for a design methodology to meet necessary conditions in the changing New Environment is urgent for both China and the world.

I kept on reflecting on these problems during my time of study, teaching and design practice in China. I had not found the opportunity to investigate solutions to these problems until, in 2000, I was granted a Huygens Scholarship by the Dutch Ministry of Education, Culture and Science, and came to the Netherlands to study in the Design Knowledge Systems Research Centers (DKS), TU Delft. My grateful thanks thus first go to the Chinese Government, CSC (Chinese Scholarships Committee), Nuffic (Dutch organization for international cooperation in Higher Education), the Dutch Ministry of Education, Culture and Science, TU Delft and DKS.

My heartfelt thanks also go to my supervisor, Professor Alexander Tzonis who is the one who has led me to the splendid shrine of scientific research in Architecture and Urban Design. I am deeply indebted to him for his innumerable and valuable lectures and discussions over the past four years. From him I learnt not only valuable knowledge but also the tenacious spirit which leads to the production of such knowledge.

I would also like to thank those Professors both inside and outside my examining committee who frequently and constantly gave me constructive suggestions and offered extremely important opinions. They are Prof. Dr. W.L. Porter, Prof. dr. D. Shefer, Prof. S. J. Doorman, Prof. Dr. R.J. Boland, Prof. Dipl.Ing H.J. Rosemann, Dr. Hoang Ell Jeng, Prof. Dr. Lam Khee Poh, Prof. Habraken, and Prof. Berkhout. I would also like to extend my gratitude to my editor Mr. Ken Fitchew who seriously and professionally edited the language of my dissertation, and Dr. R.J. Sierksma who translated part of it into Dutch. I have much appreciated discussions and debates with former and present DKS colleagues, especially Liane Lefaivre, Nan FANG, Li YU, Xiaodong LI, Karina Moraes Zarzar, Gretchen Schira, Asaf Friedman, Joo-Hwa BAY, Sinan Inanc, Sophia Vyzoviti, Predrag Sidjanin and John Linke Heintz. My special thanks go to Nan FANG, for providing and allowing the use of one of his office's designs for use as a case study. I am thankful to all students assistants in DKS, especially to Juchun Shih, and Harald Mooij who joined the 21st University's project, collected data and contributed some reports for the research. I am also indebted to Janneke Arkesteijn-Mosterd for her help in administrative matters. Thanks are also due to all the other researchers and friends who have provided help and information in the research. To my parents, my sister, Huanhuan, and Shidan, I wish to express my appreciations for their instant and constant support in my study and life, whether I am in sunlight or storms. Without them neither my life journey nor my academic journey would be possible.

Jun WU

Delft, 2004

Contents

CHAPTER 1

INTRODUCTION

Background, target problem, methods and expected outcome of the research

The target of this investigation is to develop a 'design tool' to enhance the design and planning of facilities for the sustainable production of new knowledge. More precisely, the objective is to identify a method to support the conception of building complexes related to the production of new knowledge. The tool is focused on the necessary spatial conditions which will support this end, specially the topological ones.

Today, with profound developments in what has been called the *Knowledge Economy* and consequent transitions in our society, new challenging design problems have to be faced in designing *Innovation Facilities* (IF) which are defined as facilities for production of new knowledge. It appears that one of the most crucial of these is to design *Sustainable Innovation Facilities* (SIF) which can meet the new needs and exploit the potential of the *New Environment* of our time. To solve this new problem, a new set of design methods is needed, in the form of a design tool.

This research concentrates on IF in terms of education and research complexes. Starting from methodology worked out by the Design Knowledge Systems Research Center (DKS) for the development of design tools, the research is also innovative in the following respects:

1. Transfer of *concepts and techniques* from the domains of innovation economics, regional science, environmental sustainability, and sociology to the domain of spatial design, on the scale of building complexes;

2. Development of a *model* representing spatial attributes constraining face-to-face group interaction in the built environment;

3. Development of *a design tool* which can help in evaluating and optimizing the potential diversity of groups communicating within building complexes.

This chapter introduces: the background to the research, definition of the problem of an innovative milieu, possible methods for designing such an environment, development of a design tool, and an overview of the dissertation.

1.1 Brief background: the New Environment

1.1.1 Decline of traditional welfare state institutions: dissolution of traditional boundaries between teaching, training, and research

Every epoch has its leading type of building. Today, given the leading role new knowledge plays in the world economy, innovation-producing facilities such as universities, research centers and science parks emerge as the leading building type of the twenty first century. The new knowledge epoch starts from new changes in New Environment. "*Considerable political, technological, social, and cultural developments have been redefining the university during the last decade. All these developments indicate that a New Environment has emerged, characterized by new needs as well as new opportunities. There are new potentials for collaboration, for sharing material and intellectual resources, for putting together new partnerships which cut across disciplines, professions, cultures, and public and private domains, and new avenues for mechanization and automation. The rise of new means of communication, computation, and simulation, and of new tools for the acquisition, accumulation, and dissemination of knowledge, and the explosion of specialization have disturbed the traditional idea of the university as an insular, spatially identifiable physical organization. The university organization will evolve to respond to this New Environment. There must be an equivalent evolution, that is a synergetic design response to this evolution, provided by the physical structure of the University of the 21st Century. … The appearance of the global symbolic analyst as increasingly the most ordinary producer in contemporary society has given to the university a more demanding but also a more mundane role among existing institutions*" (DKS, 2000). "*The dominance of a novel global economy and the decline of the traditional welfare state institutions have weakened the belief that the university can remain an autonomous institution. The dissolution of traditional boundaries between teaching, training, and research has overturned doctrines about its essential functions. Both purely lecturing and generating 'loose pieces of knowledge' via a traditional research assignment are no longer adequate. The blurring of established territories of work, leisure, and family life has revolutionized the character and content of its facilities*". (DKS, 2000) The main function of the university in the New Environment, as a place to create new knowledge, is sharply different from the main function of teaching in the traditional university. [1]

1.1.2 Post-industrial vs Industrial: the importance of information technology and knowledge innovation

Mumford in his book *Technics and Civilization*, first introduced the concepts of the eotechnic, paleotechnic and neotechnic periods (Mumford, 1934). In the eotechnic phase (1000 to 1800), the use of all materials, and the development of science are based on the abstraction from life of the elements that could be measured, this abstraction allowing for "corduroy roads" through basic scientific problems. The paleotechnic (roughly 1700 to 1900) is, however, "*an upthrust into barbarism, aided by the very forces and interests which originally had been directed toward the conquest of the environment and the perfection of human nature*." (p154) Inventions of the paleotechnic were made by men trying to solve specific problems rather than hunting for general scientific principles. In describing the neotechnic phase (1900 to Mumford's present, 1930), he focuses on the invention of electricity, freeing the factory production line from the restrictions of coal through the addition of small electric engines to individual machines, and freeing the laborer to create small but competitive factories. Mumford presciently notes that a small producer can deliver what is needed when it is needed more efficiently. The neotechnic phase is thus dominated by men of science, rather than mechanically apt masses of machinists.

Mumford suggests that it is necessary to understand how machines affect society and economic processes in relation to energy and life. Instead of three economic factors -- production, distribution and consumption -- he offers four economic factors: conversion, production, consumption and creation. In line with Mumford's analysis, *creation* is becoming a dominating driver of today's neotechnic economy. The creation of new knowledge in the long term is thus becoming a key issue in today's society.

Mumford's idea proceeded those of Bell (1973) who also describes three stages in the development of human society: 1) pre-industrial; 2) industrial; and 3) post-industrial. While the first two rely on economic growth organized around the dissemination of information for purposes such as social control, business efficiency, and demand management, his third stage, the 'post-industrial', relies on scientific innovation. Post-industrialism involves white-collar workers and the manipulation of information. Similarly, more recent work (Savitch, 1988) insists that contemporary developments should be seen as a transformation of the environment *from brains to*

[1] The profound influence of the New Environment on universities, and the concept of 'the university of the 21st century is systematically introduced in DKS internal report "University of the 21st Century".

hands, and *from factories to offices*. Savitch deduces the conditions applying in post-industrial cities. The first is increased competition between cities as well as between nations in terms of innovative knowledge production. The second is the complexity of building a brand new physical environment meeting the requirements of this competition. Savitch (1988: 286) points out that: "… *universities, and research centers need to be constructed with an eye toward the demographics of the twenty-first century.* " The conclusion which may be drawn from all above surveys of development can be summarized simply as: IT and Knowledge Innovation are very important in the New Environment. The question which now arises is: precisely in which locations is development occurring, and what are the spatial characteristics of these locations?

1.1.3 Localization vs Globalization: no borders and limits to interactions

The answer to the question posed above points to a pair of contradictory tendencies inherent in the New Environment: Globalization and Regionalism. The consequences of the phenomenon of globalization have been very visible since the early 1970s. City centers decline or change in form and function, new business districts or science parks spring up, immigrants or other special groups cluster together and mix with each other, new technology and new cultural enclaves are formed, and new forms of cities or new facilities are created at the edge of metropolitan areas. Marcuse and van Kempen (2000: 5) define the globalization concept as '*a combination of new technology, increased trade and mobility, increased concentration of economic control, and reduced welfare-oriented regulatory action of nation states*'. They have put forward the hypothesis that: globalization results in significant social changes and these changes will lead to new spatial orders in cities worldwide. These significant social changes can be summarized as: 1) changing forms of production; 2) a declining state provision of welfare; 3) differences in power relationships; 4) developing technologies.

Surprisingly, according to recent research, globalization starts by connecting and assimilating all components in the world, but finally turns out to lead to a degree of localization! "*Boundaries between divisions, reflected in social or physical walls among them, are increasing*" (Marcuse and van Kempen, 2000: 3). The result is a pattern of separated *clusters of spaces*. The industrial model of globalization shows that industries are organized in separated '*clusters*' in certain special regions around the world. Furthermore, Porter (1996) argues that the prosperity of countries and companies depends on the nature of the local environment in which competition takes place. In short, the more the process of globalization spreads, the greater the importance of the region. Porter defines the concept "clusters" as "*geographic* *concentrations of firms, suppliers, related industries, and specialized institutions (e.g. universities, and trade associations) that occur in a particular field in a nation, state, or city*" (Porter, 1996: 199). He insists that the cluster is a prominent feature on the landscape of every advanced economy, and cluster formation is an essential ingredient of economic development. He explains the phenomenon of cluster formation as a result of both formal and informal interactions, so that "*informal networks and formal trade associations, consortia, and other collective bodies often become necessary and appropriate*" (Porter, 1996: 258). Clusters offer: a new way of thinking about economies and economic development; new roles for business, government, and institutions; and new ways to structure the business-government or business-institution relationship. Although regionalization and the importance of localities are rising as a result of globalization, the borders of interaction between localities seem to dissolve in the tide of development of IT technology and virtual technology. The conclusion from the new change resulting from globalization is thus: on one hand there are no borders and limits to interactions; on the other hand regionalization occurs through the formation of clusters.

1.1.4 Virtual vs Physical: the importance of Person-to-Person contact

In a very widely read book Mitchell (1995) gives a comprehensive introduction to a new type of city, a largely invisible but increasingly essential system of virtual spaces interconnected by the emerging information highway. He examines architecture and urbanism in the context of the digital telecommunications revolution, the ongoing miniaturization of electronics, the commodification of bits, and the growing domination of software over materialized form. Given the growth of Internet usage, in their book 'From Web to Workplace', Gronbak and Trigg (1999) discuss the implication of hypermedia system in work, which they believe will replace its physical counterpart. However, more than a generation ago, the negative impact of new technology in communication has been observed by several researchers in reference to the impact of the telephone, television, and new means of transportation. In the 1960s and 1970s there were already studies critical of the implications of these technologies against 'place' steering the importance of space-bound interaction between people and as a consequence the significance of region and location (Webber, 1964; Chermayeff and Tzonis. 1971).

Similarly, Van Alstyne and Brynjolfsson (1996) have warned of negative consequences of high dependence on Internet, which they term 'Cyberbalkanization'. They maintain that organizational structures are changing in E-society. The plummeting costs of IT have changed the relative efficiency of different structures for coordinating work in companies and markets and in universities (Noam, 1995). The consequence turns out to be contrary to the original assertion that the World Wide Web would build broader, richer, scientific communities. Therefore, Van Alstyne and Brynjolfsson assert that if IT technology helps a knowledge producer in one domain spend more time interacting with colleagues globally, this will be to the detriment of his or her interactions with the other knowledge producers in other domains? Kuhn (1962) identified the widening gulf between scientific specialists more than three decades ago. Today, geographic balkanization, which separates scientists in physical space, is giving way to electronic balkanization, which separates them in "*topic space*".

The debate about the preferability of face-to-face contacts in physical places versus contacts through alternative 'media' in virtual places is at least fifty years old. During the 1950s and 1960s, the impact of telephones, television, and closed circuit TV technology was observed. Today the debate concerns the impact of email and virtual reality computerized systems. Actually, virtual and physical means each have advantages and disadvantages. What is needed is contact by BOTH virtual media AND face-to-face encounter, which are not mutually exclusive. Achieving a balance between them is fundamental in constructing a sustainable human society. Therefore the importance of physical Person-to-Person contact is put forward here as a parallel strategy to the use of virtual media in order to maintain long-term innovation.

1.2 Problem statement: What are the required spatial attributes for a 'Sustainable Innovation Facility' in the New Environment?

1.2.1 The challenge in the New Environment

Considering these significant changes in the New Environment, the key challenge for the New Environment may be summarized follows:

1. The world needs to increase growth and output year on year, or at least maintain them at the same level.

2. In order to achieve this growth over the long-term, it is necessary to adapt to the changing environment, taking account of factors not normally considered in promoting short-term growth.

3. More than anytime before there is a need for facilities designed to take account of the conflicting priorities of increased growth and long-term adaptation.

In other words, this poses the question of how sustainable facilities can be designed which promote both production and adaptation long-term?

This challenge is usually investigated in terms of “Sustainable Development” (see chapter 2 of a detailed discussion of Sustainable Development). It is acknowledged as one of today’s most widely discussed issues, an issue that has implications in many varying contexts. So far, there is no commonly accepted final definition of Sustainable Development. However, it is widely accepted that the ‘Basic Features’ of Sustainable Development can be summarized as: a process of increasing output or at least maintaining it at the same level under a changing environment through adaptation to the changing conditions. Current literature on ‘Sustainable Development’ has demonstrated that most research has focused mainly on the construction of a ‘sustainable economy and environment’ and not enough on the construction of ‘sustainable innovation’, or the production of new knowledge. However, ‘sustainable innovation’ plays an even more important role in maintaining continuous growth in economy and minimizing pollutions in environment. This research thus investigates how to design facilities that potentially promote the sustainable production of new knowledge.

The research departs from the assumption that a *necessary* condition for adaptation towards sustainable innovation is diversity among the interacting knowledge producers. This is identified as the diversity of resources of knowledge made available to researchers. To maintain such a condition a facility has to support on the one hand processes of differentiation and specialization of knowledge, and on the other, accessibility to such specialized and differentiated knowledge resources.

The objective of sustainability for facilities for innovation is of equal value to that of efficiency and effectiveness. Originally used to characterize and evaluate economic relations between humans and resources in developing societies, sustainability has been expanded to include relations between human practices and the natural ecological environment. It now relates to processes or states of an environment, such as those of diversity of interactions and knowledge innovation in the present research project, that have to be maintained over long periods. For long-term innovation, diverse interactions are constantly needed. Florida (2004) indicates how diversity dramatically influences the potential for innovation. He uses a ‘creative index’ to measure the ability for knowledge production in various cities in the USA. The Creativity Index is thus his baseline indicator of a region's overall standing in the creative economy and he offers it as a barometer of a region's longer-term economic potential. He used tables to present the creativity index ranking for the top 10 and bottom 10 metropolitan areas, grouped into three size categories (large, medium-sized and small cities/regions) His conclusions are very clear: the higher the diversity in a city, the greater its creativity! Florida also points out that the key to economic growth lies in the abilities not just to attract the creative class but to translate that underlying advantage into creative economic outcomes in the form of new ideas, new high-tech businesses and regional growth.

The joint objective of enhancing both efficiency of knowledge specialization and sustainability of knowledge diversity, suggests the need for a generic, complementary integration of electronic media for virtual communication and a spatial physical circulation network that provides for person-to-person contact. Within such a system, electronic media link researchers with sources of knowledge all over the globe as well as with each other. The spatial structure supports face-to-face encounters of researchers within the facility. The presence of both systems, the electronic and the physical, assist the clustering of people as well as the diversity of their interaction. The first is biased towards clustering of specialization, and the second, which might operate with redundancy and low efficiency from the point of view of promoting the exchange of information between specialists, however improve physical diversity of interaction.

In short, the basic features of Sustainable Development may be summarized as: Process of progressive output or at least maintenance of the same level, under changing environment through adaptation condition. A necessary condition for such adaptation is the existence of physical interaction between diverse knowledge producers to counter the negative impact as ‘Cyberbalkanization’ on physical diversity, which results when interaction between knowledge producers is only carried out through global E-access. Hence, to combine advantages from both virtual and physical means in the New Environment, diverse physical interactions are stressed inside current Innovation Facilities. The next question is, how to design such Sustainable Innovation Facilities?

1.2.2 Summary of the problem in the New Environment

The study of changes that brought about the New Environment has shown that, the creation of new knowledge is the primary task in today’s society. The long-term creation of new knowledge relies heavily on diverse face-to-face and virtual interactions as one of the necessary conditions[2]. It is important to underline that the

[2] This is true also in the design side of the research. The aim is to develop a design tool that controls the necessary environmental conditions for innovation. In other words, the goal is to define the conditions which are necessary for the formation of diverse clusters in a building complex. However, it is clear that simply arranging that diverse people can meet is not a sufficient condition for the to production of new knowledge. Other factors may be equally or more important, such as: incentives in the society that would reward innovative behavior; a market for the products of innovative activity; organization that promotes and supports innovation through a variety of means including but not limited to space and facilities; etc.

proposed system deals with a necessary, physical, built environment condition for the production of new knowledge. Such conditions are not sufficient to ensure effective interaction and certainly not sufficient to ensure the production of new knowledge. To enhance the physical interactions among diverse researchers in the New Environment, we urgently need a design tool to assist the design of Innovation Facilities in which such diverse face-to-face interactions can potentially be promoted by architectural layouts.

The research thus has been circumscribed by the need to acquire design models which represent potential face-to-face interactions among diverse researchers in built spaces and solve these problems for Innovation Facilities in the New Environment.

1.3 Method of investigation into how to design SIF in the New Environment

1.3.1 Developing a tool for designing SIF

The choice of a tool to help design SIF must take account of the significant social, cultural, and technological changes that are currently redefining traditional building types, as described previously. The research is positioned in the context of the new needs and opportunities that are reinterpreting the university as a work place producing, rather than only reproducing, knowledge, and are revolutionizing its operations through the use of the new electronic media of computation and communication. What is of the essence therefore is that the spatial organization of these facilities should be beneficial for creative work over a long period of time.

1.3.2 What the tool is expected to achieve

In considering the design of Innovation Facilities, the project will take account the two available major means of communication in our time: the electronic, in virtual space, and face-to-face interaction in a physical, architectural space. It will concentrate, however, on examining the built environment. The reason for this option, as will be discussed later, is that current investigations report that on one hand electronic processing and communication media are highly efficient in advancing interactions between specialists promoting the division and differentiation of knowledge while, on the other hand, over time, they lead to information exchange in cliques and to segregated clusters of specialists. In this manner, the *long-term* effect of electronic communication media, left on their own, has an negative impact on the potential creation of new knowledge in Innovation Facilities. It may advance diversity as such in the short term, but in the long run it may reduce the diversity of interactions of researchers within the facility. If virtual means are only used by themselves, therefore, they lead to *non-sustainable* innovation.

In addition, as some studies have also shown, the topological organization of locations and access to a facility, and the facility's topological circulation network constrain the potential flow of people within it. In this manner the topological network affects the potential diversity of encounters between people within the facility, influencing *if and when* they meet face to face. The layout can enhance the clustering of specialists but it can also maximize heterogeneity and the potential mixing of knowledge groups, thus promoting diversity of interaction. It has an impact therefore, on what may be identified as the diversity potential in the innovation environment and it can thus provide conditions which support the production of innovative knowledge within the facility over a long period.

From this starting-point, the present investigation concentrates on the development of a design tool to generate spatial arrangements for Innovation Facilities that satisfy the necessary conditions for maximizing the potential for diverse encounters between people. The tool is employed in achieving what is called the diversity potential of the innovation environment. This is in contrast to previous studies, which mainly stress the physical qualities of the environment. Starting from the premise that individuals in contact with books, with other information media, and with their physical surroundings invent and innovate in solitude, other studies have concentrated on the physical quality of an environment, aiming to make it comfortable and "inspiring" for creative researchers.

The target is, therefore, a design tool having the following functions:

1. To develop a model to represent and investigate the topological layout and allocation of meeting locations in Innovation Facilities. (This will be investigated in Chapter 7: Archigraph);

2. To develop a model to represent and investigate social relationships (especially the exchange of information within a social network) agents meeting in Innovation Facilities (This will be investigated in Chapter 6: Sociogram);

3. To develop a systematic theory framework to deal with the issue of 'physical interaction of diverse researchers' within a facility. (This will be investigated in Chapter 8: The Design Tool).

1.3.3 Methods to be used to construct the tool

The project involves generating a model representing the potential flow of information within space, and as an outcome of the model it can help evaluating and optimizing the potential diversity of groups communicating within building complexes. . The methods to be used to construct the design tool will be mainly drawn from the Design Knowledge Systems Research Centre (DKS) and summarized as:

1. Multi-disciplinary investigations leading to knowledge transfer;
2. Domain theories (State of the art in programmatic and spatial analysis studies);
3. Case studies for deepening the understanding of the problem;
4. Focus on the necessary spatial design conditions;
5. Means-ends Analysis[3] applied to development of the tool.

More precisely, faced with the newness and complexity of the problem we drew from work already achieved in:

1. Sociology of scientific innovation;
2. Cognitive science;
3. Ecological and economic studies;
4. Regional science;

It will also be necessary to rely on the use of Multiple-criteria method (Tzonis and Salama, 1972; Shefer and Voogd, 1990) to help generate the optimum compromise solution in situations where there are multiple incommensurable criteria and Case study method (Yin, 1994).

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[3] Means-ends analysis is a method always applied in artificial intelligence to understand the relationship between goals (Newell and Simon, 1972). In this problem-solving procedure, to achieve one goal (end), we need one means; while in the next turn this means is the goal to be achieved. Therefore, the means of former turn is the goal of the next turn, and the goal of the next turn is the means of former turn.

In Winston's research, he calls this procedure a 'state space' in which each node denotes a state, and each link denotes a possible one-step transition from one state to another state, or in another word, the beginning means is a initial state, the final end is a goal state (Winston, 1992). "The purpose of means-ends analysis is to identify a procedure that causes a transition from the current state to the goal state, or at least to an intermediate state that is closer to the goal state. Thus, the identified procedure reduces the observed difference between the current state and the goal state."

Winston also points out that: to perform means-ends analysis, until the goal is reached or no more procedures are available, we have the steps below:

1.Describe the current state, the goal state, and the difference between the two.

2.Use the difference between the current state and goal state, possibly with the description of the current state or goal state, to select a promising procedure.

3.Use the promising procedure and update the current state.

If the goal is reached, announce success; otherwise, announce failure.

The Means-Ends analysis of design tool development can be summarized as follows:

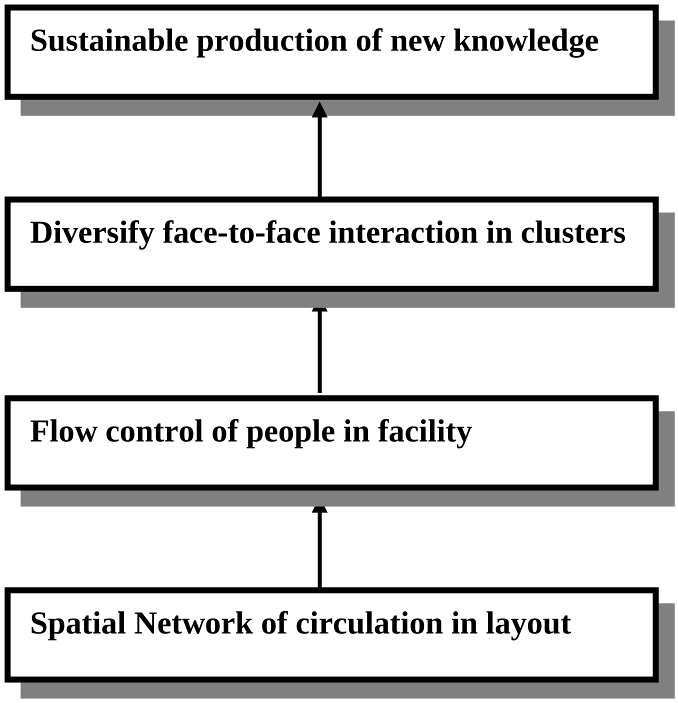

Figure 1.1: Means-Ends Analysis of Design Tool Development

To identify the main problem and to generate a framework for the design tool, an initial case study was proposed as part of the research. In this first case study, a typical Innovation Facility, Delft University of Technology was taken in order to provide familiarity with the problems in existing Innovation Facilities and to develop some adequacy criteria for the design tool. This design tool, 'DNAS' (**D**iversity **N**etwork **A**nalysis **S**ystem) is intended to measure and control interaction profiles in which the *Diversity Index* is a key parameter. Some examples have been taken to illustrate the uses of such a tool in helping to solve different problems in both design generation and design evaluation, including deciding the best allocation, and choosing the topological layout and the typological layout of Innovation Facilities.

1.3.4 Method of testing the tool

To test this design tool, the second case study was proposed as part of the research. This involved comparing two alternative innovation facility projects in a real design situation. With the aid of the design tool, it is easy to deduce which project will have a better performance of potential interaction of diverse researchers. The aim of the case study was to test the effectiveness of the tool and to make possible modifications

1. 4 Outline of the dissertation

The dissertation outline is summarized in Figure 1.2.

Chapter 1 presents a brief background to the research: the statement of the problem, the methods to solve it, and the possible outcome of the research.

Chapter 2 examines the concept of ‘sustainability’ in relation to the development of innovative knowledge in the New Environment, and its application in designing Innovation Facilities. ‘Sustainable Innovation Facilities’ (SIF) are defined accordingly, and the necessary criteria for SIF are suggested. It examines the concept of ‘Diversity’ and identifies individual diversity and group diversity in relation to Innovation Facilities.

Chapter 3 investigates the concept of ‘Cluster’. It suggests some criteria and methodologies to promote the maximum diversity of interaction in clusters of in Innovation Facilities. Several types of clusters are identified.

Chapter 4 describes the first case study. The factors constraining the potential for meeting in knowledge production facilities are analyzed, and the problems with current Innovation Facilities in the New Environment are outlined.

Chapter 5 reviews existing theories relating to Innovation Facilities. It presents an analysis of their advantages and disadvantages in helping in the design of Innovation Facilities. In addition it provides a rough framework for a design tool which can solve most of the new problems in Innovation Facilities by applying aspects of these theories.

Chapter 6 investigates existing theories regarding social relationships, and develops an initial model to be used later in the design tool, more specifically, based on the “*Sociogram*”. Sociograms are used here to represent relations influencing information flow among agents in Innovation Facilities.

Chapter 7 presents some existing architectural representation theories which deal with teaching and research building complexes and develops a model for application in the design tool, introducing aspects of physical space by means of an “*Archigraph*”.

Chapter 8 uses the two models developed in the previous two chapters to construct the design tool, which is called ‘DNAS’ (Diversity Network Analysis System). In addition, a number of examples are taken to illustrate various possible usages of the ‘DNAS’.

Chapter 9 takes a real design case in order to develop a framework for testing the tool 'DNAS'. The design tool is used to identify and analyze the spatial conditions that make one design solution better than another in providing a high potential for diversity of interaction. Possible modifications of the tool are also discussed.

Chapter 10 draws conclusion for the whole dissertation and proposed an extension for future research.

Chapter 1 **Introduction**	Brief introduction of the target, methods, outcome, and procedure for the study
Chapter 2 **Diversity for Sustainable Innovation**	Review of 'sustainability'; common criteria for sustainability; definition of 'sustainable Innovation Facilities' in the New Environment. Review of 'Diversity'; identify individual diversity and group diversity
Chapter 3 **Clusters in Innovation Facilities**	Introduce concepts of 'Cluster' in diversity; identify their applications in SIF
Chapter 4 **Use of a Case Study to Identify Issues Relating to Innovation Facilities**	Design the case study of TU Delft; analyze and identify problems occurring in the case study; provide possible criteria to construct the design tool
Chapter 5 **Existing Theories Relating to Innovation Facilities**	Review main existing theories of Innovation Facilities; compare their advantages and disadvantages; summarize the need for a new theory
Chapter 6 **Representing Social and Information Flow Relationships: the Sociogram**	Introduce 'Sociogram'; the process of generating a Sociogram for Innovation Facilities.
Chapter 7 **Representing Topological Constraints: the Archigraph**	Review methods to represent buildings; identify model 2 'Archigraph'; the process of generating an Archigraph.
Chapter 8 **The Design Tool: 'DNAS'**	Construct the design tool 'DNAS'; enumerate examples of using the tool to evaluate and generate design, considering all possible combinations of allocation, topology and typology
Chapter 9 **Testing the Tool and Proposals for Modifications: Case Study 2**	Test the tool 'DNAS' in a real design case
Chapter 10 **Conclusions and Extension**	Generalize and extend of possible usages of the tool in other domains. Conclude the research and promising research in future.

Figure 1.2: Outline of the dissertation

CHAPTER 2

DIVERSITY FOR SUSTAINABLE INNOVATION

Defining the goal of designing environments for the long- term generation of new knowledge

The previous chapter introduced the background and framework of the whole research theme. We stressed the importance of continuity in the production of new knowledge, a concept which has been called “sustainability”. This chapter will examine both the concept of ‘sustainability’ in relation to the development of new knowledge, and its application in designing physical facilities. We will accordingly define ‘Sustainable Innovation Facilities’ (SIF) in which the concept of ‘diversity’ is a necessary condition. We will study ‘diversity’ in the fields of ecology and social science, and transfer it to the field of Innovation Facilities. By Innovation[1] Facility[2] (IF) we mean the physical

[1] There are many definitions of innovation. If we look on the web, a reference commonly used today, innovation is mainly defined as follows:
Definition 2.1.1: A creation (a new device or process) resulting from study and experimentation.
Definition 2.1.2: Applications of new knowledge in a way that creates new products or significantly changes old ones.
Definition 2.1.3: The generation and exploitation of new ideas. The process moves products and services, human and capital resources, markets and production processes beyond their current boundaries and capabilities.
Definition 2.1.4: Often used as an alternative to "inventions" and is used to cover both technological advances in production processes as well as the introduction of different attributes and combinations in marketable products. (Pearce, 1996)
Definition 2.1.5: The process by which new products or new methods of production are introduced.
Definition 2.1.6: The whole process from, invention, development, pilot production, and marketing, to production.
Definition 2.1.7: “An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption” (Rogers, 1995: 11). The “carrying out of new combinations, such as the introduction of a new good, the introduction of a new method of production, the opening of a new market, the opening of a new source of supply, or the reorganization of any industry…” (Schumpeter, 1934: 66)
These definitions stress different aspects from which we can attempt a kind of composite that defines innovation as an evolving process that generates new objects or ideas, including new knowledge of processes which can lead to modeling new kinds of objects often using recourse to prior knowledge.

[2] Similarly, drawing from the web again, we will try to define ‘facility’ as:
Definition 2.2.1: Facility means any equipment, structure, system, process, or activity that fulfils a specific purpose. (DOE Order 5500.1B)
Definition 2.2.2: The buildings, equipment, structures, and other stationary items which are located on a single site or on contiguous or adjacent sites and which are owned or operated by the same person, or by any person who controls, is controlled by, or is under common control with, such person.
Definition 2.2.3: Facility includes data about the combinations of physical, financial, and human resources that are used to provide or receive services.
Definition 2.2.4: Property used for academic activities, maintenance, research, development or testing.

infrastructure consisting of built and open air, designed parcels of space, used by individual and groups, and providing for supporting mechanical devices whose purpose is to produce new knowledge in the long term. Therefore, university campuses, science parks, and office buildings can be seen as typical facilities for innovation. Here we will be concerned with the identification of the essential physical characteristics of Innovation Facilities, which are necessary conditions for the sustainable production of new knowledge. However before that we have to investigate what sustainable development is in relation to Innovation Facilities?

2.1 From sustainable economy and environment to the sustainable production of new knowledge

As mentioned, the aim of the research is to develop a tool for designing facilities which are to produce new knowledge over long periods of time, in other words, sustainably. We have now to explore the concept of sustainability in the economy, and in environmental studies to see the degree to which it can be used in the domain of the production of new knowledge[3].

One of key criteria that we will extract from the sustainable economy and environmental systems is the criterion of diversity. Again, as mentioned at the beginning of this dissertation, it is critical to understand that the criterion of diversity for promoting sustainable innovation is definitely a necessary condition but it is not alone sufficient.

2.1.1 Sustainable economy and sustainable environment

Sustainability is a fashionable term today. It is used in several overlapping ways. As we did with the 'innovation' and 'facility', to avoid confusion we will try to define 'sustainability'. In doing so, however, 'sustainability' [4] being a more technical concept, we will refer to specialist literature rather than the web references.

Definition 2.2.5: A physical element of infrastructure, intended to provide support, shelter, or otherwise to facilitate economic or social activities and thereby accrue benefits for humanity.

Facility is thus defined as: any physical elements (equipment, structure, system, process, space or activity) of infrastructure that fulfils a specific purpose to facilitate economic or social activities and thereby accrue benefits for humanity, and store or transform inventory. These elements of infrastructure are located in a concentrated site, or on contiguous or adjacent sites. They are combinations of physical, financial, and human resources that are used to fulfill such a specific purpose. To form a facility, the necessary characteristics required are: 1.Specific purpose (see definition 2.2.1); 2.Concentrated location (see definition 2.2.2); 3.Combination of physical, as well as and human resources (see definitions 2.2.4); 4.Objective of facilitating economic or social activities (see definitions 2.2.6)

[3] The general systems method provides such a possibility to transfer knowledge from the previous two domains to the domain of knowledge production. We will see how sustainability in the economy and environment relate to the sustainability of the production of new knowledge conceptually, but not how sustainable ecology and a sustainable economy contribute to sustainable knowledge innovation, although they do actually contribute to this. It would be too complex to include this here.

[4] "Sustainable" is actually derived from the Latin verb "sustinere" and describes relations (processes or states) that can be maintained for a very long time or indefinitely (Judes 1996). But with only the long term as a criterion, this might fail to explain complex situations that are based on conflicting structures or competing trends. Thus, it is easy

Vital documents were presented in some significant International Conferences[5] which highlighted the development of the concept: 1) Stockholm Conference 1972[6]; 2) Brundtland Report 1987 in the International Union for the Conservation of Nature[7]; 3) Rio de Janeiro UNCED Conference 1992[8]; The Kyoto Agreement 1996[9]. Besides these, more than 60 definitions[10] are to be found in literature (Marien, 1996). Originally, the concept was initiated in relation to environmental concerns and was associated with "conservation" movements in the USA in the 1930s, which formed an attempt to "really organize resource exploitation and regional economic planning" (O'Riordan, 1981).

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to understand why, in the context, sustainability should be identified as a criterion for the evaluation of human relations with the environment and of human social conduct which cover social interaction in knowledge producing.

[5] When in 1962 the UN published *The Development Decade: Proposals for Action for the first development decade(1960-70)*, optimism about the development efforts of the 1950s was still high. UNRISD's publication of the International Development Strategy in 1970 was proposed to announce a new form of integrated development which took account of the global interaction of resources, technology, economic forces and other factors leading to social change. About the same time a UN resolution called for nations to adopt a unified approach to ensure several laudable objectives: 1) all social groups should benefit from development; 2) all nations and all groups within each nation should be provided with the means, in the form of structural change, to take part in development; 3) development should promote social equality; 4) development should fulfill human potential.

[6] In 1972, in Stockholm, "Only One Earth" became the motto of the first UN conference on Human Environment (UNCHE). (Clarke and Timberlake, 1982).Some members of the international community believed that progress toward protection of the environment was necessarily linked to progress in the elimination of poverty throughout the world.

[7] In 1980 the International Union for the Conservation of Nature adopted a world Conservation Strategy that called for a sustainable use of species and ecosystems. However, the concept was not pushed to a prominent peak until 1987, when the Brundtland wrote the WCED's report "Our Common Future". Environmental deterioration identified in the report can be summed up as: 1) rapid loss of productive dry land that was being transformed into desert; 2) rapid loss of forests; 3) global warming caused by increases in greenhouse gases; 4) loss of the atmosphere's protective ozone shield due to industrial gases; 5) the pollution of surface water and ground water. (WCED 1987).

[8] In response to Our Common Future, in June of 1992, another important United Nations Conference on Environment and Development, generally known as the Earth Summit, was held in Rio de Janeiro. Five key documents were signed that will be implemented in the years ahead and that will keep sustainable development in the center of international affairs. They were: 1) the Treaty on Climate Change, 2)the Treaty on Biodiversity, 3)the Convention on Forest Principles, 4)the Rio Declaration, 5)Agenda 21. Among these, Agenda 21 may prove to be the most prominent of all the Earth Summit agreements. This is because it is a blueprint for international action in the coming 21st century. It contains 40 chapters focused on solving the twin problems of environmental protection and sustainable development. Each of the 40 chapters defines a statement of objectives, an outline of required activities, guidelines for developing a framework of action, necessary institutional changes, and identification of the needs of implementation, including indications of necessary research and a financial and cost analysis.

[9] After the Rio conference emphasizing the social and cultural issues, the Kyoto summit was held in 1996 to achieve more concrete measures especially in emissions reductions. Under the Kyoto proposal, participating nations agreed to bring average greenhouse gas emissions over the period 2008 to 2012 back to the 1990 levels. To follow this agreement, the industrialized countries need to take action in three areas:
1) reduction in energy consumption; 2) replacement use of energy from fossil reserves by use of energy from renewable sources; 3) carbon storing. To implement this protocol, representatives from 180 countries met in Den Haag and set levels of reductions in emissions of CO_2 and 5 other greenhouse gases for 38 countries of the industrialized world. Due to disagreements between Europe and the USA, the conference ended in failure. In 2002, the conference "Rio +10" was held in Johannesburg to initiate a fresh round of talks.

[10] Important definitions include: **Definition 1** (WCED 1987): "…meets the needs of the present without compromising the ability of future generations to meet their own needs…"; **Definition 2** (IUCN/UNEP/WWF, 1991): Sustainable development is a process of "improving the quality of human life within the carrying capacity of supporting ecosystems". This definition includes three basic key concepts: 1) a co-evolutionary concept of humans and nature; 2) the socio-cultural concept of human needs and 3) the natural science concept of the (limited) ecosystem; **Definition 3** (Buzas 1991): "Sustainable development, by contrast, is not something as concrete as a procedure for reviewing development project proposals. It is a concept that functions as both a goal in the world of actual decisions and as an evolving idea. In the later context, it is an idea that may never be reached but which is still the lodestar of a new vision of human society."; **Definition 4** (UN Secretary-General Boutros-Ghali 1992): Sustainable development is the development which "meets the needs of the present as long as resources are renewed or, in another words, that does not compromise the development of future generations" (Johnson, 1993; Lemons and Morgan, 1995); **Definition 5** (Dumreicher, Levine, Yanarella and Radmard, 2000): "Sustainability is a local,

During the 1950s and 1960s increasing material flow in the economies that had supported economic growth since the end of the Second World War revived concerns about the continued availability of resources, and the term became limited to economics.

In the 1980s, the United Nations World Commission on Environment and Development coined the most widely used definition of sustainable development, associating it with development "*meeting the needs of the present without endangering the ability of future generations to meet their own needs*" [11] (Bruntland, ed, 1987). In other words, sustainable development did not mean a return to a pre-industrial era, but calls for **continued** economic **growth**, acknowledging responsibility for its continuous impact. This became even clearer in the Earth Summit held in Rio de Janeiro in June 1992.

Starting from existing official documents[12] from International Organizations and Non-governmental Organizations, different aspects of sustainable development have been emphasized at different times[13]. However, two main aspects seem to be always

informed, participatory, balance-seeking process, operating within an equitable ecological region, exporting no problems beyond its territory or into the future".

[11] In the report of the world commission on Environment and Development "Our Common Future", it is also mentioned that: "sustainable development is …development that ensures that the utilization of resources and the environment today does not damage prospects for their use by future generations" and "must take account of social and ecological factors, as well as economic ones; of the long-term as well as the short-term advantages of alternative actions." "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future…But sustainable development means that growing economies remain firmly attached to their ecological roots and that these roots are protected and nurtured so that they may support growth over the long term. Environmental protection is thus inherent in the concept of sustainable development, as is a focus on the sources of environmental problems rather than the symptoms."

"… an approach to development aimed at harmonizing social and economic objectives with ecologically sound management, in a spirit of solidarity with future generations, based on the principle of basic needs, a new symbiosis of man and earth; another kind of qualitative growth, not zero growth, not negative growth."

"In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."

[12] In the process of seeking sustainable development, a lot of international, regional or national organizations and policies have been established. In the UNCED's "Earth Summit" mentioned earlier, the membership states of the international community were preparing and publishing national sustainable development plans and strategies, and submitting these to found a special international organization ---UNCSD (the UN Commission for Sustainable Development). It was finally founded in December 1992, to monitor the worldwide progress towards the implementation of Agenda 21 and other Rio documents. The CSD meets once a year for a period of two to three weeks at the UN headquarters. Besides these efforts, several nations have initiated significant national sustainable development programs. These include: The Netherlands National Environmental Policy Plan (NEPP); the Canadian National Task Force (NTF); and the United States President's Council on Sustainable Development (PCSD). Some of the most significant international agreements also include: 1) 1972 London Dumping Convention; 2) 1982 UN Convention on the law of the sea; 3) 1985 Vienna Convention for the Protection of the Ozone Layer; 4) 1989 Basel Convention on the control of Transboundary Movement of Hazardous Wastes and Their Disposal; 5) 1994 the Program of Action on World Population agreed to at UN's conference on Population and Environment at Cairo; 6) 1995Agreements reached at the UN world Summit for Social Development in Copenhagen.

[13] There are three main aspects stressed: the environmental aspects; the economic aspects; and the social aspects. Buzas (1991) recognizes sustainable development as value systems and policy frameworks in which three circles (economic goals; environmental goals; and social goals) interact with each other. Munasinghe (1993) also identifies the interacted loop of these three essential axes (objectives) of sustainable development in the diagram below:

stressed: economic concerns and environmental concerns in which two basic criteria are 1) long-term growth; 2) an adaptation in a way that seeks a balance between priorities.

From the economic viewpoint, sustainable development seeks long-term growth in the economy while simultaneously reducing the negative by-effects of externalities by means of balance-seeking adaptation[14]. Many economists focused on this issue and made contributions for varied solutions for better adaptation to sustain long-term growth. All these efforts mainly concentrated on two points: 1) how to maintain growth; and 2) how to maintain growth over the long term by adaptation. Diversity of resources as well as diversity of products in the economy has an irreplaceable role in constructing a better adaptation system.

Similarly, in the environmental and ecological domains, adaptation is also an important means to maintain sustainable development in changeable conditions. The environmental crisis originated from the pressures of economic growth[15]. To reach the

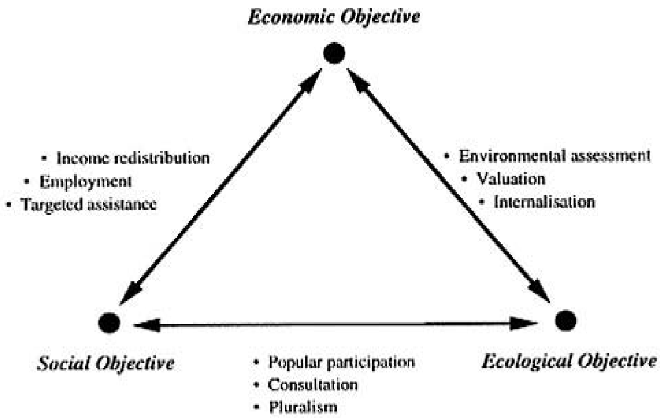

Figure 2.1: The three main objectives of sustainable development (Source: Munasinghe, 1993)

[14] In the colony economies from the 16th to 19th century, the colonists occupied a region and forced all the traditional industries in that region to be abandoned in favor of producing only one kind of special product (for instance: sugar industry in Central America; forestry and cotton industry in the South-east Asia area; mineral industry in Africa). In the short term, the production did reach its peak. However, in the longer term, when another region emerged with cheaper labor or other advantages in competition, the mono-industry of the previous region declined sharply and eventually the economy of the whole region died. From this lesson, economists learnt that the mono-industry or mono-culture economy was a major obstacle to maintaining long-term economic growth in a region. Or putting it another way, diversity in economy can maintain longer-term economic growth because it provides a better potential performance of balance-seeking adaptation in a changing world market.

In the 1910s and later in the 1930s, economic crisis spread from the regional to the global scale and twice contributed to World Wars. From the Marxist point of view it was thought of as an inevitable result of the Capitalist system, while later studies argued that economic crisis could be avoided by some better balance-seeking adaptations, and that the traditional economic system could be revised, so leading to renewal of the world economy. By the 1950s the world economy was beginning to suffer another kind of crisis from the enlarging gap between the developed world and the developing world. Furthermore, even inside the developing countries there was an enlarging gap between the rich and the poor.

[15] In 1966 Kenneth Boulding, an English-born Professor of economics in the USA, used the image of the spaceship in addressing the question of material growth in a paper entitled “The Economics of the Coming Spaceship Earth”. He contrasted two basic models of the economy. One was called the “cowboy economy” which is characteristic of open societies, and another was called the “spaceship economy” which operates within a closed system with finite

maximum growth in the economy with the lowest costs, first, the economy tries to grab and exploit as much natural resource as possible, and second it does not care about any externalities (mostly varying kinds of pollutions) that are byproducts of its production. When the conflict between the pressure for economic growth and the need to preserve the environment became sharply defined, the focus on concerns about growing global pollution and the population situation[16] increased. The ability to assimilate industrial externalities and adapt to a changing environment also relies heavily on the same attribute: diversity. In 1980, the publication of the World Conservation Strategy (WCS), provided a compact but comprehensive set of environmental objectives that societies would have to meet to ensure continued, that is sustainable, global habitability, which included: 1) the preservation of genetic *diversity*; 2) ensuring the sustainable utilization of species and ecosystems. To maintain sustainability in ecosystems, normatively, "*Ecosystems tend to become diversified and stable. The extent of information which they contain determines their diversity, the various feedback mechanisms which exist within them maintain their stability and achieve a steady-state relationship between the component pollution and communities and their environment*[17]." (Buzas, 1991: 13).

limits. (Boulding, 1992, p31). Despite the elitist and technocratic associations of the spaceship metaphor, the two ideas of resources being part of a system with finite limits and of conserving capital stock found ready acceptance in several quarters.

A few years later, an American economist, Nicholas Georgescu-Roegen, wrote a book entitled *The Entropy Law and the Economic Process*. He developed his thesis that "the basic nature of the economic process is entropic and that the Entropy Law reigns supreme over this process and over its evolution"(Georgescu-Roegen,1971, p283).He points out that economic activity speeds up the entropic process, adding to the constant automatic "shuffling" of entropy in the environment. Applying the laws of thermodynamics, Georgescu-Roegen (1971, p281) also points out that the economic process neither "creates nor consumes matter or energy, but only transforms low into high entropy". He was quick to point out that acceptance of the notion that any use of energy has an entropic "cost" and that any economy has finite limits should immediately raise questions of priority in a world of scarcity or potential scarcity.

In 1972 the British magazine *The Ecologist* published *Blueprint for Survival*, in which it was proposed that a stable society required: 1) the minimum of disruption of ecological process; 2) maximum conservation of materials and energy; 3) a population in which recruitment equals loss; 4) a social system in which people are able to enjoy rather than have to endure the conditions in which they live.

Within a few months of the *Blueprint for Survival*, the Meadows' team published *Limits to Growth*, in the form of a report to the *Club of Rome*. It attracted great interest. The world conservation strategy has three main objectives: to maintain essential ecological processes and life-support systems; to preserve genetic diversity; and to ensure the sustainable utilization of species and ecosystems.

Generally, there are two kinds of ways to bring the total ecological impacts of economic activity within the sustainability boundary: extending the ecological boundary, or reducing the economy's consumption of natural capital. To reduce the economy's consumption of natural capital, Paul and Ann Ehrlich (1990) gave the possible formula as: **I=PCT** (**Equation 2.1**), in which

I= the total ecological or environmental impact of the economy; P= the size of the population; C= the average material standard of living, or per capita consumption of resources; and T= the state of technology, or the ecological efficiency of the economy.

Even if C and T remain constant, any increase in P will make it more difficult to observe sustainability constraints. Because many resources are in greater supply in the South, then population growth is not just a problem in the South (Ehrlich and Ehrlich, 1990).

16 In the mass of statistics three main issues stood out: 1) The increase in human-related activities and their impacts, and an accompanying decrease in the resources of the Planet. (MacNeill, 1989; Brown et al, 1991; Vitousek et al, 1986); 2.) Growing inequality between rich and poor---between rich and poor nations and between rich and poor within some countries (Elliot, 1994; Rowntree Foundation, 1995; Commission for Social Justice, 1994); 3) Excessive Population Growth (WCED, 1987; Ehrlich and Ehrlich, 1990; Harrison, 1992; Brown, Flavin and Kane, 1994).

17 Buzas (1991) also argued that: "Ecosystems are not however static when stable. Information is constantly being accumulated as they continue to adapt and evolve. This accumulating information permits further adjustment between the biotic component of ecosystem and the abiotic element of environment. This process is the ecological succession."

The conclusion is that to maintain long-term stability in environmental and economic systems, adaptation to changing conditions and increasing pressures is crucial. In the process of adaptation, diversity is an important and effective element. This conclusion is very useful for the development of our tool to enhance the design of facilities producing new knowledge in the long term.

2.1.2 Basic criteria for a sustainable system

From the previous investigation of the concept of 'Sustainability' it is found that both sustainable economy and sustainable environment share the same requirements:

1. To maintain resources for keeping up a productive state;
2. To adapt to changes in the new environment over the long term.

From the above discussion, it may be concluded that in a non-sustainable system, the development aims at certain growth objectives but ignores the need for adaptation to change in the new environment over the long term. In the short term it can maximize the growth. However in the long term, because of the lack of *adaptability*, the system decreases fatally and collapses. Conversely, in a sustainable system, the development aims at certain objectives but taking account of possible changes in the future via adaptation, the growth in the system can be steady and continuous over the long term. In the process of adaptation, all possible impacts and risks which might jeopardize the potential for growth are remedied by balance-seeking adaptation over the long term. Both sustainable process and unsustainable process are represented in a figure below:

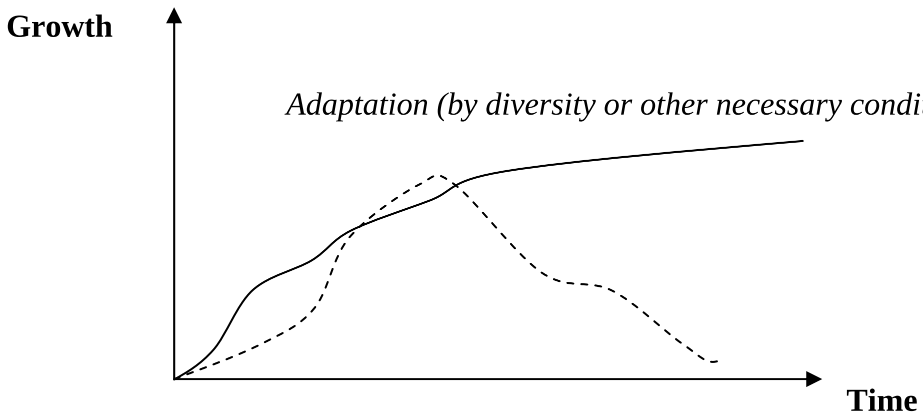

Figure 2.2: Long-term growth vs time (the continuous line represents a sustainable process and the dashed line an unsustainable process)

There are various means of implementing adaptation. Diversity in the system is one of the most common means of contributing to this. Whether we are considering sustainable economy or sustainable environment, diversity plays a vital and irreplaceable role. The next question is: can we validly transfer this knowledge from the areas of sustainable economy and sustainable environment to the domain of the sustainable production of new knowledge? Can such a transfer of principles suggest a physical means, related to facilities, which might help such production?

2.1.3 Sustainable Innovation Facilities

In the previous two sections, two main sustainable systems have been analyzed and the basic criteria have been extracted from them. In this section we will try to apply the knowledge from these sustainable systems to sustainable Innovation Facilities. To transfer knowledge from one system to another, a general systems approach is introduced. A systems approach[18] is, generally, applied to problems characterized by large number of highly and dynamically interrelated parts. The idea of the systems method can be adopted for our problem in aspects of integrating between different systems (Clayton and Radcliffe, 1996). The general systems approach is, however, applied in order to cope with highly complex problems which are difficult to analyze. It transfers knowledge from one domain and projects it into another, to form a hypothesis and eventually build a model. Therefore, the general systems approach has a more concrete application in our research while transferring knowledge from sustainable economy, sustainable environment and other domains to sustainable innovation system.

According to the general system method we can transfer relevant knowledge from the areas of the environment and economics, and so we can accordingly define criteria for sustainable Innovation Facilities which are similar to those applying to economic sustainability and environmental sustainability, namely:

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[18] System is defined as "an interconnected set of elements, with coherent organization". More precisely, we will focus on specific aspects of systems characterized by hierarchy structure, emergent properties, communication, and control which displays adaptive, dynamic, goal-seeking, self-preserving, or evolutionary behavior. (Checkland, 1981; Gleik, 1987; Meadows, 1992; Clayton and Radcliffe, 1996)
If we use the systems method for controlling sustainable development, we find that all 4 dimensions should be considered, and the mutual interactions between them should also be taken into account. In fact, Buzas (1991) and Munasinghe (1993) have described this mutual loop in sustainable development (see figure 2.2). We develop this system view of sustainable development with all criteria included in a diamond structure which covers: 1: Economic Objective; 2. Ecological Objective; 3. Social Objective; 4. Knowledge Objective (see figure 2.3). The first 3 objectives occur on the level of interaction between people and environment; however the 4th objective introduced by us will focus on the level of interaction between people and people.

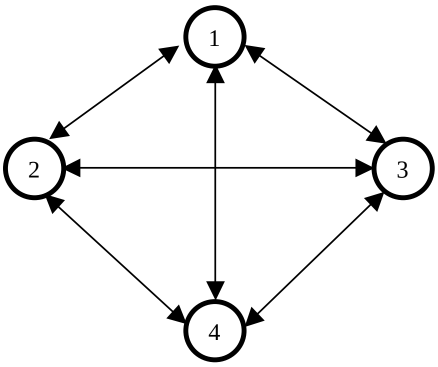

Figure 2.3: A Diamond Structure of Four aspects of Sustainable Developments (1: Economic Objective; 2. Ecological Objective; 3. Social Objective; and 4. Knowledge Objective)

1. Maintenance of resources for ensuring a knowledge productive state;

2. Adaptation to changes in the new environment over the long term.

Because of the differences between different systems, these have to be transferred according to the specific characteristics of the system appropriate to Innovation Facilities. In Innovation Facilities, the resources for maintaining a productive state are researchers who bring knowledge and information together to produce new knowledge. The means of adaptation to change is the same as it is in sustainable economy and environment: diversity in the system. Consequently, a sustainable innovation facility is a physical infrastructure whose purpose is to produce new knowledge in the long term supported by two basic conditions: maintaining the resource of researchers in interacting group, and adaptation to change via diversity in the interacting groups. The importance of diversity for a sustainable environment and sustainable economy have been established. However, the importance of diversity in sustainable innovation is borrowed from the previous two systems, the economy and the environment, and so has to be studied in its own context. Considering the transfer from sustainable economy and environment to sustainable innovation facilities, we identify diversity as a basic criterion for adaptation, which is useful in maintaining a sustainable system, and naturally which is applicable in the other sustainable systems including sustainable Innovation Facilities. From another viewpoint, considering its own context, the next section will establish the importance of diversity in sustainable innovation by citation and analysis.

2.2 Why diversity is important for sustainable innovation?

2.2.1 Innovation follows from diversity

As argued by Galison (1999), a historian of science at Harvard, creative science and technology always result from previous knowledge and previous technology, which explains the secret of innovation from the historical viewpoint. Innovation is thus a transferring between previous knowledge and new knowledge. During this transfer, a necessary condition for new knowledge production is to provide the potential chance to consult and draw on previous knowledge. There are mainly two kinds of resource of previous knowledge: static knowledge stored in books, and dynamic knowledge and information gained by researchers. The second kind is more advantageous since the knowledge is developing and evolving. In particular, when researchers from different disciplines meet, the knowledge they have is exchanged and may potentially be developed into new knowledge. It is very clear that the more difference there is between two earlier sources of knowledge, the more innovative the integration of these two existing sources of knowledge may be, and hence the more innovative may be the synthesized new knowledge. The greater the difference between the disciplines and the academic background they come from, the higher the potential value for the production of new knowledge.

There are also two kinds of contacts between these researchers: virtual means and physical means, both of which have their own irreplaceable advantages in communications. The differences between these two means will be discussed in the next chapter. As pointed out, the design of the physical architectural layout which potentially determines whether these researchers can meet or not, is our research priority. It is certain that both the virtual and the physical environment can provide such interaction between different researchers, and both have their irreplaceable values. Physical face-to-face interaction is identified here as only one of the main necessary conditions to promote such meeting potential.

In short, new knowledge is created from previous knowledge. During the process of interaction and integration between elements of previous knowledge, the more difference there is between the disciplines of the researchers, the more innovative the new knowledge developed. As one of the necessary conditions, potential physical face-to-face interaction among these diverse researchers is fundamental. Or in other words, innovation follows from diversity.

In addition, many other researchers have proved the importance of diversity in promoting long-term creativity in Innovation Facilities. Since the 1960s, several studies in the University of Michigan have revealed that heterogeneous groups produced more creative solutions to assigned problems than homogeneous groups (Harvey and Allard, 2002). Florida (2004) takes a Creativity Index as the baseline indicator of a region's overall status in the creative economy and offers it as a barometer for a region's *longer run* economic potential. '*Creative index*' is used to measure the ability to produce knowledge in various cities in the USA. It indicates how diversity dramatically influences innovation potential. His discovery is prominent: the greater the diversity in a city; the more creative it is! Florida further points out that the key to economic growth lies in the ability not just to attract the creative class, but to translate that underlying advantage into creative economic outcomes in the form of new ideas, new high-tech businesses and regional growth over the long term. Again as concluded by Galison, new knowledge mostly comes from previous knowledge, as in the case of the importance of creativity in cities introduced by Florida. Basically the observation that idea-generation is becoming more significant is not a particularly novel observation. After all, Smith (first published 1776, 1904 the 5th edition) emphasizes the importance of knowledge-creation. Marshall (1920) is generally credited with beginning the modern discussion of idea-generation in urban economies. Jacobs (1984) in her book '*Cities and the Wealth of Nations: principles of economic life*' is also about creativity, especially in urban areas.

Similar ideas about creativity in urban areas were recently presented in a book by Hall and Landry (1997): 'Innovative and sustainable cities'. Landry (2000) in his more recent book: *The Creative City: A Toolkit for Urban Innovators*, reveals the secret of urban creativity. He enumerates eight foundations of the *creative city*, among which two are particularly interesting: (1) human diversity and access to varied talent and mixing people, and (2) networking and associative structures. His theory provides us with both the ends and means for developing a more creative city. It is thus clear that to establish a more creative milieu, it is necessary to mix diverse talent with both physical and virtual access with each other. To have such physical accesses with other diverse talents, networking (in terms of clusters) provides an ideal unit and structure for the potential physical accesses in architectural layouts. Boland (1995: *350*) insists that '*knowledge-intensive firms are composed of multiple communities with specialized expertise, and are often characterized by lateral rather than hierarchical organizational forms'*. This view indirectly supports the argument that *multiple communities*, or in other words diversity in clusters, is fundamental for producing new knowledge, although Boland focuses on the role communication plays in the process of innovation.

Harvey and Allard (2002: 23) forecast four trends[19] which will impact diversity initiatives in the future. In trend 2 (Virtual Companies), it is expected that, companies will increasingly become "*a web of informational relationships…." "Most workers are in knowledge or service jobs; ..." "The networks require that diverse people work together…to maximize creativity and flexibility in order to be competitive*". Significant consultants, academics, and business leaders have advocated that organizations respond to these trends with a "valuing diversity" approach. They suggest that a well-managed, diverse workforce holds potential competitive advantages for organizations (Roosevelt, 1990; Copeland, 1988; Mandrell and Kohler-Gray, 1990; Etsy, 1988; Sodano and Baler, 1983). It is concluded that, " *organizations that fail to make appropriate changes to more successfully use and keep employees from different backgrounds can expect to suffer a significant competitive disadvantage compared to those that do*" (Cox and Blake, 2002: 48 in *Understanding and Managing Diversity readings, cases, and exercises*). In the creativity argument, it is suggested that diversity can improve the level of creativity. Advocates of the value-in-diversity hypothesis advise that work team heterogeneity promotes creativity and innovation (Johnston and William 1990; 1991). Subsequent researches tends to support this kind of relationship. Kanter (1983: 167) revealed that the most innovative companies deliberately establish heterogeneous teams to "*create a marketplace of ideas, recognizing that a multiplicity of points of view need to be brought to bear on a problem*." Nemeth found that minority views could stimulate consideration of non-obvious alternatives in task groups. She further

[19] These trends include: Trend 1: Internationalization; Trend 2: Virtual Companies; Trend 3: Decentralization of Power; Trend 4: Prejudice and Discrimination (Harvey and Allard, 2002).

concludes that the groups exposed to minority views were more creative than the more homogeneous, majority groups, and continual exposure to minority viewpoints encourages processes of creative though. Nemeth's research concludes that the heterogeneous teams were more creative than the homogeneous ones; hence, diversity can increase team creativity and innovation. (Nemeth, 1986; Triandis and Ewen, 1965) By means of links between diverse areas, concepts and products, and also information and technologies transfer from one culture to another. As one sign of post-industrialization, the workforce has become increasingly *diverse* in order to face increasing competitiveness in the market (Sowell, 2002 in *Understanding and Managing Diversity - Readings, Cases, and Exercises*). It is believed that powerful social forces are combining with diversity concerns to change social circumstances and mandate organizational change (Harvey and Allard, 2002). All these researches draw the similar conclusion that innovation follows from diversity. The next question raised is: does diversity help long term innovation?

2.2.2 Long term innovation follows from diversity

As concluded in the previous section, diversity is a basic and effective means of adaptation in sustainable systems of the economy and the environment, and also in the system of sustainable innovation. This is also easily understood. Suppose researchers in the same or similar disciplines are isolated on an island where they can only contact or meet other researchers from their own domains. They have neither physical nor virtual means to approach the researchers from the other 'islands'. In the short term, they do produce some new knowledge from the previous knowledge everyone takes with them. However, in the long term, both the amount and the quality of the new knowledge they produce can decrease. Because of the lack of diversity in the disciplines where the researchers come from, they tend to produce similar knowledge or at least produce new knowledge only on the basis of the similar previous knowledge. As a consequence, in the long term, they tend to produce less and lower quality new knowledge, because they can only build on the same previous knowledge. Furthermore, because of the lack of diversity in the disciplines where the researchers come from, once they leave the island and return to a changed and updated normal society, even if the discipline where they come from was very advanced, the new knowledge they produced on the isolated island has a very high risk of being behind the times, because of the lack of diversity to provide an effective and basic means of adaptation. If the researchers in the other domains are also isolated on their own islands, then similar unsustainable innovation will occur for them too. This kind of isolation can be identified as 'geographic balkanization'.

On the other hand in the rising virtual world, as mentioned in chapter 1, Van Alstyne and Brynjolfsson (1996) identified another kind of isolation, which they term 'Cyberbalkanzation'. Van Alstyne and Brynjolfsson suggest that, if IT technology helps knowledge producers in one domain spend more time interacting globally with colleagues working in the same domain, this may result in a reduction in interactions with other knowledge producers in other domains? Nowadays, geographic balkanization, which separates scientists in physical space, is giving way to electronic balkanization, which separates them in "topic space".

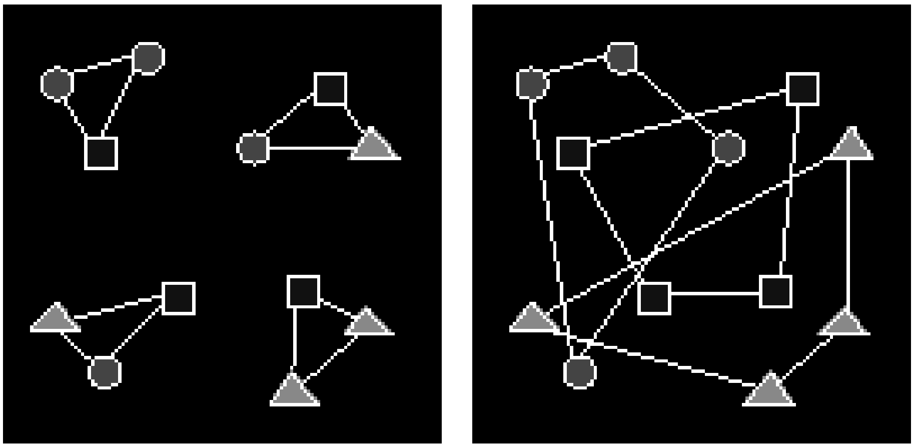

Figure 2.4: IT can reconstitute geographic communities by research discipline. (Source: Van Alstyne and Brynjolfsson, 1997)

Van Alstyne and Brynjolfsson further point out that information technology can reconstitute geographic communities (see left panel of Figure 2.4) into communities corresponding to research disciplines (see right panel). They further calculate that the level of balkanization may increase as developments in technology result in improvements in searching, filtering, and long-distance collaboration. They conclude that unless scientists actively seek diversity, global E-access might lead to a state in which balkanization limits interactions. This kind of isolation will again lead to the unsustainable production of knowledge.

Therefore lack of diversity in interaction may cause 'geographic balkanization' and 'Cyberbalkanization' both of which may lead to unsustainable production of knowledge. The enhancing of diversity in physical milieu can potentially decrease the possibility of both 'geographic balkanization' and 'Cyberbalkanization', thus promoting the long term production of new knowledge.

In short, long term innovation follows from diversity in physical interaction, although innovation does not just depend upon diversity[20]. Therefore, diversity in physical

[20] Innovation might follow a lot of other necessary factors: the people, the organization, the virtual environment, the change processes, etc. However, here we mainly focus on diversity as one of the main necessary conditions for

interaction is one of the important necessary conditions in promoting sustainable innovation in the New Environment. It requires diverse researchers to work face-to-face together to maximize creativity and flexibility in order to remain competitive over the long term. The next question is: how can we define, identify and measure the diversity in interacting groups of researchers. What can we learn from similar systems in which diversity is a crucial means and measure of adaptation to maintain long-term stability and growth?

2.3 How to identify, measure, and represent diversity in an Innovation Facility?

Having defined the objective of sustainable knowledge production for the development of a tool to facilitate the design of supporting facilities, we turn now to the definition of the concept of the diversity of people interacting. In order to define more precisely how to analyze the role of differences among the people or groups in interaction, so enhancing the production of new knowledge, we will look at how diversity is represented and measured in other domains. Then, according the general system method, we can transfer the knowledge of diversity in other domains to the diversity in the domain of Innovation Facilities. The question which concerns us from the point of view of knowledge production (given as we have seen the fact that differences in the background of people interacting contributes to sustainable knowledge generation) is therefore how diversity can be represented and measured. For this we will turn to other fields where diversity has been studied and modeled, such as ecology and social science.

2.3.1 Diversity in Ecology

The major applications of diversity measurement are in nature conservation and environmental monitoring. In both situations diversity is held to be synonymous with ecological quality. However, the techniques of defining, measuring, and representing diversity in the ecology domain can be used by analogy for diversity in interacting individuals and groups in Innovation Facilities.

2.3.1.1 Definition of diversity in ecology

sustainable innovation. Even diversity has its own risk over the long term. Basically, innovation is not sustainable when a system is not opened up. The reason for that is that closed systems do not permit a growing diversity. Again this is a long discussion because we know that an open system might also invite its own destruction.

The notion of 'diversity' in the natural world was first discussed as early as the end of the 19th century (Clements, 1916; Thoreau, 1860) and remains a central theme in ecology today (Currier and Paquin, 1987; May, 1986). A definition of diversity in biological science21 is as follows: Diversity refers to the characteristics of a community consisting of organisms of different species. In common language it often expresses solely the variety, i.e. the number of species. In ecological terms it also expresses the evenness of the distribution of the species (Huisman, 1995).

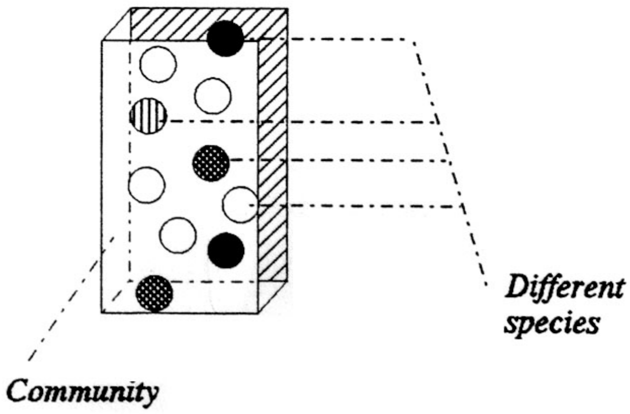

Figure 2.6: Schematic representation of diversity (Source: Huisman, 1995, p15)

2.3.1.2 Measurement of diversity in ecology

[21] According to Huisman (1995) there are two other conceptions relating to the conception of 'diversity': 'differentiation' and 'diversification'. Diversification refers to processes in which the diversity of a system increases, whether by means of the growth of the number of species or by means of a change in the dispersion of the organisms across the species. Diversification can be seen as the dynamic counterpart of diversity. In biological sciences, the term differentiation refers to the emergence of several parts out of a formerly integrated whole, each fulfilling its own function as part of the larger whole. Differentiation denotes a dynamic process.

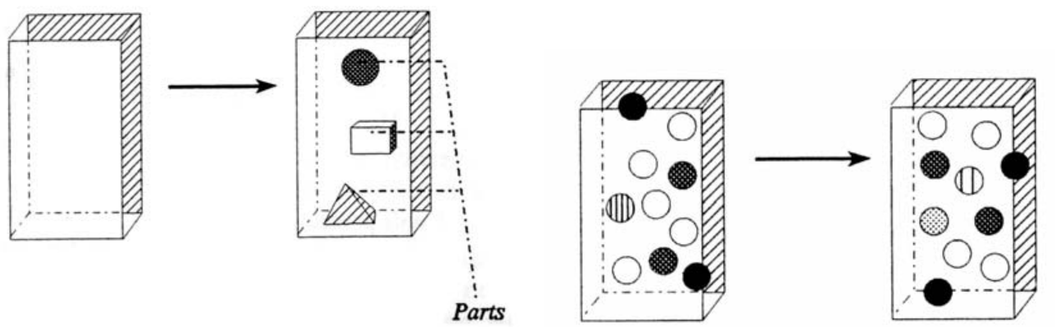

Figure 2.5: Schematic representation of differentiation (Left) and diversification (right) (Source: Huisman, 1995, p14, p17)

Table 2.1: Three biological concepts on two dimensions (Source: Huisman, 1995)

Concepts	Static/dynamic	Unit of research
Differentiation	dynamic	integrated whole
Diversity	static	organisms of a community
Diversification	dynamic	organisms of a community

Measurement of individuals' differences

Measurements of diversity in ecology are usually seen as indicators of the well being of ecological systems. Although ecologists have devised a huge range of indices and models for measuring diversity, considerable debate still surrounds the measurement of diversity. Diversity is hard to measure since it consists of not one but two components, namely the variety and the relative abundance of species. However, diversity can be measured at least by recording the number of species, by describing their relative abundance or by using a measurement which combines the two components (Magurran, 1988). Diversity measurements can thus take into accounts at least two basic parameters: *species richness*, that is number of species, and *evenness* (something known as equitability), that is how equally abundant the species are. High evenness, which occurs when species are equal or virtually equal in abundance, is conventionally equated with high diversity. Many of the differences between indices lie in the relative weightings that they give to evenness and species richness[22]. Species richness provides an extremely useful measure of diversity. However if a sample rather than a complete catalogue of species in the community is obtained, it becomes necessary to distinguish between numerical species richness, which is defined as the number of species in a specified number of individuals or amount of biomass (Kempton, 1979; Bunce and Shaw, 1973; Kershaw and Looney, 1985), and species density, which is the number of species in a specified collection area (Hurlbert, 1971; Homer, 1976) [23].

Measurement of groups' differences

To measure the differences among groups in ecology, it is necessary first to identify the groups in the community. Krebs (1985) defines a community as 'a group of populations of plants and animals in a given place' while Begon *et al.* (1986) describe it as 'an assemblage of species populations which occur together in space and time'. Southwood (1988) sees a community as an organized body of individuals in a specified location. In all these representative definitions in ecology, the identifying of a community tends to

[22] Species diversity measures can be divided into three main categories. The first is the species richness indices which are essentially a measure of the number of species in a defined sampling unit. The second is the species abundance models which describe the distribution of species abundance. The third is the indices based on the proportional abundances of species forming the final group. In this category come the indices such as those of Shannon and Simpson, which seek to crystallize richness and evenness into a single figure. (Magurran, 1988)

23 Hurlbert proposed an unbiased estimate to replace Sanders's Rarefaction formula:

$$E(S) = \sum \left\{ 1 - \left[\binom{N - N_i}{n} \Big/ \binom{N}{n} \right] \right\}$$

(**Equation 2.2**)

where E(S)=expected number of species; n=standardized sample size; N=total number of individuals recorded; N_i=number of individulas in the ith species. Diversity is usually examined in relation to four main models which include: the log-normal distribution, the geometric series, the logarithmic series and MacArthur's broken stick model.

follow two basic criteria. First of all, a community is made up of a group of interacting organisms. This group may be as restricted as a single cohort or may embrace everything from bacteria to buffalos. Secondly, the community exists within defined spatial boundaries. Thus we can refer to a community of insects on a bracket fungus, a community of plants in a field or a community of plants and animals in a tropical rain forest. The need to define and delimit the community will arise in any investigation of ecological diversity (or even diversity in a community of researchers in sustainable Innovation Facilities). Whittaker (1972, 1977) introduces the notion of *inventory* diversity. He (1977) distinguishes four levels of inventory diversity. On the smallest scale is *point* diversity which is the diversity of a micro-habitat or sample taken from within a homogeneous habitat. The second of Whittaker's categories is termed *alpha* diversity, and is directly equivalent to MacArthur's (1965) idea of within-habitat diversity. The third scale of inventory diversity is *gamma* diversity which is the diversity of a larger unit such as an island or landscape. As gamma diversity is defined to be the overall diversity of a group of areas of alpha diversity so *epsilon* or regional diversity, the fourth category is the total diversity of a group of areas of gamma diversity. Begon *et al.* (1986) argue that 'a community can be defined at any size, scale or level within a hierarchy of habitats and give examples of three scales: the flora and fauna in a deer's gut, the beech/maple woodland within which the deer is found and the temperate forest biome of North America. It is unlikely that any decision about the physical boundaries of the study area will be made independently from the choice of the group of organisms to be studied. For instance Southwood et al. (1979) concluded that insect diversity was actually related to plant taxonomic diversity in the early stages of a fallow field changing to birch woodland. Hence, the measurements of diversity in groups are applied to fairly limited, well-defined, taxonomic groups.

Niche width measurement

No matter whether we are measuring individual differences or group differences, niche width provides a measurement of the breadth or diversity of resources used by an individual or species. The usual approach[24] is to use either the Shannon index[25] or the Simpson index[26] to calculate the width of the niche. The number of resource categories observed (for example, types of food eaten, varieties of habitat utilized, kinds of behavior employed) replaces the number of species in the equation. For instance,

24 Useful models and theories were developed by Colwell and Futuyma (1971), Feinsinger et al. (1981), Griller (1984), Hurlbert (1978), Southwood (1978) and Thormon (1982).

25 Equation of the Shannon index: $H' = -\sum p_i \ln p_i$. The quantity pi is the proportion of individuals found in the ith species. (**Equation 2.3**)

26 Equation of the Simpson index: $D=\sum (n_i(n_i-1)/N (N-1))$ where ni=the number of individuals in the ith species and N=the total number of individuals. (**Equation 2.4**)

Kotrschal and Thomson (1986) measured the trophic diversity, that is the width of the feeding niche, of 34 species of Pacific blennioid fish[27].

Guidelines for the analysis of diversity data have been proposed as follows (Magurran, 1988):

1. Ensure where possible that the sample sizes are equal and large enough to be representative;
2. Draw a rank abundance graph;
3. Calculate the Margalef and Berger-Parker indices;
4. Determine log series α ;
5. Test the fit of the main species abundance models formally;
6. Test for significant differences between communities;
7. Use the jack-knife procedure to improve the estimate of a diversity statistic;
8. Be consistent in choice of diversity index.

The key steps can be summarized as: decide on an ideal sample size; draw a graph; calculate; compare differences; generate a diversity index.

2.3.1.3 Representation of diversity in ecology

The models used to measure diversity in ecology consequently determine the ways to represent diversity. Generally, the diversity in ecology can be represented in: 1) Mathematical equations; 2) Statistical tables; 3) Analysis figures; 4) Scatter graphs. In total, at least 13 kinds of statistical models have been used to represent diversity in ecology, including: 1) α (log series); 2) λ (log normal); 3) Q statistic; 4) S (Species richness); 5) Margalef index; 6) Shannon index: 7) Brilloutin index; 8) McIntosh *U* index; 9) Simpson index; 10) Berger-Parker index; 11) Shannon evenness; 12) Brilloutin evenness; 13) McIntosh *D* index[28]. Most of they concentrate on evenness and richness.

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27 The gut contents of the fish were identified and the abundances of over 70 categories of food types estimated. The trophic diversity of each species was then calculated using the Shannon index. These measures of trophic diversity were used to distinguish three categories of fish: 1) specialists (6 species); 2) low diversity feeders (18 species); 3) high diversity generalists (10 species).

28 Both advantages and disadvantaged, and scope of application of these 13 models can be roughly compared in a table shown below.

Table 2.2: A summary of the performance and characteristics of a range of diversity statistics (Source: Magurran, 1988, P79).

	Discriminant ability	**Sensitivity to sample size**	**Richness or evenness dominance**	**Calculation**	**Widely used**
α (log series)	Good	Low	Richness	Simple	Yes
λ (log normal)	Good	Moderate	Richness	Complex	No
Q statistic	Good	Low	Richness	Complex	No
S(Species richness)	Good	High	Richness	Simple	Yes
Margalef index	Good	High	Richness	Simple	No
Shannon index	Moderate	Moderate	Richness	Intermediate	Yes
Brilloutin index	Moderate	Moderate	Richness	Complex	No
McIntosh *U* index	Good	Moderate	Richness	Intermediate	No
Simpson index	Moderate	Low	Dominance	Intermediate	Yes
Berger-Parker index	Poor	Low	Dominance	Simple	No

2.3.1.4 Possible application to the diversity of Innovation Facilities

From the diversity in ecology it is possible to extract some general knowledge which can be transferred to controlling the diversity in Innovation Facilities. Accordingly, it defines: *Diversity in Innovation Facilities refers to the characteristics of an academic community consisting of groups of different researchers.* Whether we are measuring individual diversity, or group diversity, two criteria are always essential: species richness and evenness. The key steps mentioned above for measuring diversity are equally fundamental in measuring diversity in Innovation Facilities: decide an ideal sample size; draw a graph; calculate; compare differences; generate a diversity index. In representing diversity in Innovation Facilities, a graphical representation seems to a clearer and fuller perception of the key issues.

However, how to precisely identify and represent the diversity in individuals or groups of researchers in Innovation Facilities is still too vague. The systems used in ecology seem to be inadequate. It is therefore useful to look at the study of innovation in social science, which is far more complex than it is in the ecological world. In ecology, by measuring species richness and evenness, diversity is also measurable. The objects in the ecological world are plants and animals which can be isolated, observed, measured, and tested (of course, human beings are also a part in the ecological system in the purest sense). In contrast, social systems are very complex, impossible to isolate, and hard to test[29]. To have a better understanding of diversity in a social system, it is necessary to analyze in-depth how to measure diversity in a social system as an Innovation Facility.

2.3.2 Individual Diversity and Group diversity in an Innovation Facility

2.3.2.1 Definition of individual diversity in Innovation Facilities

The definition of individual diversity in workforce research[30]covers a multitude of social, cultural, physical, and environmental differences among people which impact

Shannon evenness	Poor	Moderate	Evenness	Simple	No
Brillouin evenness	Poor	Moderate	Evenness	Complex	No
McIntosh *D* index	Poor	Moderate	Dominance	Simple	No

29 The difference between social systems and the other systems in the world was identified by Prof. S. J. Doorman, when he gave an internal lecture to DKS members. He claims that the social system is more complex and more different from the other systems due to the following reasons: 1) any social system (even an individual in prison) cannot be isolated (like ecological objects); 2) The social process is hard to be re-produce (like chemical or physical experiments act in a closed tube); 3) the result of a so-called 'social experiment' is hence not as reliable as the result of experiments in the other systems.

30 There are three phases which are milestones in research into the complexity of the diverse workforce:

1. The social movements of the 1960s and 1970s which led to important diversity legislation.
2. Understanding differences was emphasized, meaning gaining awareness of the cultures, values, and sensitivity to the characteristics of individual groups.

on the way they think and behave. Aspects of individual diversity include race, ethnicity, gender, physical abilities, sexual orientation, age, religion, social class, and many other dimensions (Harvey and Allard, 2002). Loden and Rosener (1991) see diversity as "this vast of physical and cultural differences that constitute the spectrum of human diversity". Roosevelt (1992) refers to "the whole nature of the modern workforce---in terms of age, educational differences, background, nationality, and a multitude of other factors".

2.3.2.2 How to identify individual diversity in Innovation Facilities

There are two ways to define individuals in identifying group diversity, which include an independent construal of self and an interdependent construal of self. The first is usually seen in western cultures, while the second is common in eastern cultures. Loden (1996) provides the dimensions of a diversity model based on the first approach (an independent construal of self). In his model, individuals are defined and distinguished from each other in terms of both first and second dimensions.

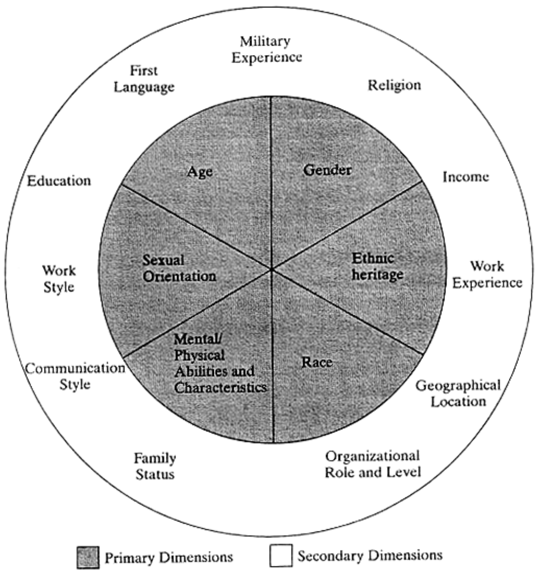

Figure 2.7: Dimensions of Diversity (Source: from Loden, Implementing Diversity, 1996, Business One Irwin, p. 16.)

In contrast, the Szapocznik and Kurtines model is based on an interdependent construal of self approach, which rests upon the individual's group memberships. In this model, actors may wear several layers of clothing. Departing from these, Locke has

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3. The current phase is called managing differences which is based on the premise that organizations can learn to 'manage' people's differences in ways that will make workers more productive and more compatible team members.

developed a more comprehensive interdependent model to represent awareness of self and awareness of cultural diversity, in which an important concept is 'community'.

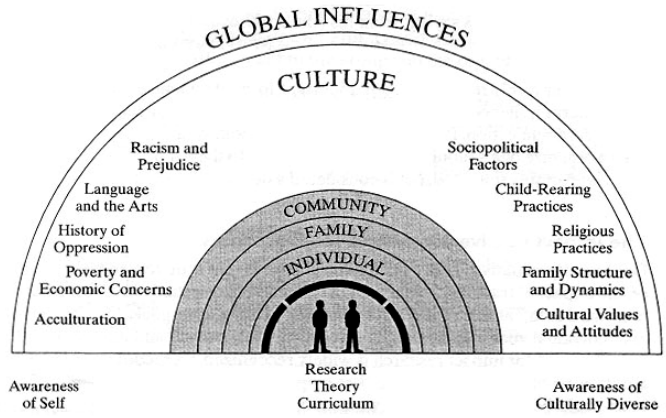

Figure 2.8: Multicultural Understanding (Source: From Locke, *Increasing Multicultural Understanding: A Comprehensive Model*, 2/e, 1998, p.2.)

The updated changes of research in this domain of workplace diversity can be summed up as: 1) Shift from individual diversity to organizational diversity (group diversity); and 2) Shift from first aspects to secondary aspects such as social class, religion, military experience, communication style, nonprofit organizations, and international business (Harvey and Allard, 2002). The first shift advises that organizational aspect shall be introduced into Locke's model, which will go through the other circles in Locke's model. The second shift proposes that a third dimension shall be introduced into Loden's model, to directly represent differences of disciplines between individuals and between groups.

Consequently, Loden's model is transformed into a new model with three dimensions which include differences between disciplines, to identify differences in individuals and groups in Innovation Facilities. This is an adaptation to the second shift which illustrates the emphasis shifting from core to the peripheral dimensions.

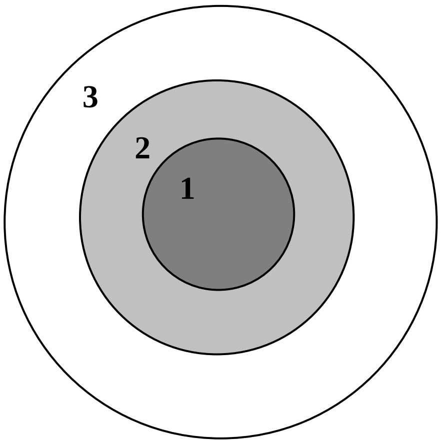

Figure 2.9: 3 Dimensions of Diversity in workplace of sustainable Innovation Facilities (1. first dimensions; 2. secondary dimensions; 3. third dimensions: Differences of disciplines)

Accordingly, the organizational axis is introduced in Locke's model, which bridges different scopes of differences by organizational fabric.

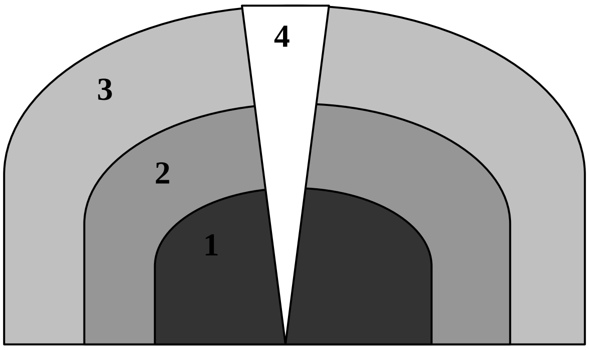

Figure 2.10: Multidiscipline Understanding (1. individual; 2. cultural; 3. global; 4 knowledge cluster.)

2.3.2.3 Definition of group diversity in innovative facilities

Studies involve maintaining group diversity in Innovation Facilities (mainly in terms of higher education systems) worldwide. However, the purposes, instruments, and results of the diversity policies diverge far away from each other. In the context of Innovation Facilities, the term diversity generally refers to establishing or maintaining differences between entities-institutions, programs, and sectors of the higher education system (Huisman, 1995). The term diversity can be used to refer to the variety of types of entities (such as higher education institutions, study programs, disciplinary cultures) within a certain system (the higher education system, a sector of the system, a university) or to a combination of the variety of types and the dispersion of entities across the types ('type' is chosen to be analogous to species). There are two kinds of diversity, sometimes overlapping with each other, the systemic diversity and the programmatic diversity. Systemic diversity refers to differences between institution type, size, while programmatic diversity refers to the degree level, degree area, comprehensiveness, mission, length of nominal study duration, and emphasis of the programs of the institutions (Huisman, 1995). Huisman's research also focuses on three dimensions: process (differentiation) versus product (diversity) studies, theoretical versus atheoretical studies, and interpretative versus operationalistic studies.

2.3.2.4 How to identify group diversity in Innovation Facilities

Clark (1979) insists that: "(group) Diversity is the name of the whole enterprise in higher education". He (1978) emphasizes that the study of diversity must not be limited to describing the partition of people across parts of the organization, but should include the processes of power and power legitimization. He (1983) argues that the increased complexity of higher education systems is related to the increased complexity of the tasks the systems must fulfill. Increased complexity is a function of three interrelated forces: 1) increase in the variety of the student population; 2) growth of the labor market for higher education graduates; 3) emergence of new disciplines. The emergence of new disciplines, however, relies heavily on interaction across disciplines both at an organizational level and at a spatial organizational level in the campus, especially in connection with the dilemma mentioned in the previous chapter on the New Environment.

Despite being highly complex, the group diversity in Innovation Facilities can be observed from the perspectives of external diversity and internal diversity, which were first proposed by Stadtman and Birnbaum (1980, 1983). External diversity31relates to differences between organizations with regard to Innovation Facilities. Internal diversity relates to differences within an organization with regard to Innovation Facilities. Huisman (1995) proposes a category of differences between external diversity and internal diversity between organizational groups in Innovation Facilities.

Table 2.3: A classification of studies on forms of differentiation and diversity (Source: Huisman, 1995)

Forms	**Higher education studies**
External diversity	Classification, typology, comparison of institutions
Internal diversity	Classification, typology, comparison of disciplines
Differentiation[32] of roles and functions	Differentiation of functions, roles and structures

To clarify the difference between differences within institutions and differences between institutions, Clark derives four units: tiers, hierarchies, sections and sectors.

Table 2.4: Dimensions and units of academic (Source: Huisman, 1995)

	Within institutions	Between institutions
Vertical	TIERS: Undergraduate, graduate, professional school	HIERARCHIES: Status, prestige
Horizontal	SECTIONS: Faculty, school, college, chair, department	SECTIONS: Public vs. private, university vs. non-university

Similarly, Blau and Schoenherr (1971) distinguish several dimensions of group diversity, which together constitute the structure of an organization. The first, or horizontal, dimension relates to subdividing organizations into divisions, departments and sections. The second, or vertical, dimension relates to the functional hierarchies (administrative levels) within the organization. The third dimension relates to the division of labor. The fourth refers to the geographical spread of parts of the

31 Based on Stadtman's (1980) work, Birnbaum (1983) distinguishes internal and external diversity in detail. He (1983) identifies seven forms focusing especially on external diversity: 1) systemic; 2) structural; 3) programmatic; 4) procedural; 5) reputational; 6) constituential; 7) values and climate. To evaluate the change in institutional diversity in the American higher education system between 1960 and 1980, Birnbaum builds a typology of institutions based on the following variables: 1) control; 2) size; 3) sex of students; 4) program; 5) degree level; 6) minority enrolment.

32 Rhoades (1990) argues that the emergence of new structures and functions is important in processes of differentiation. He refers to Smelser's (1959) unique definition of differentiation: "structural differentiation is a process whereby one social role or organization …differentiates into two or more roles or organizations…". Rhoades (1990) thinks infusion is important: "Changes in higher education may involve the 'infusion' of new concerns and the construction or recasting of organizational units to work in accordance with these." Over time Clark

organization. The third dimension of difference between disciplines seems to highlight the investigation between disciplines differences. Blau insists that increasing size generates structural diversity along various dimensions at decelerating rates, creating mutual dependencies between groups is crucial to integrating people (seems to weave these organizations in groups of clusters) 33. The fourth dimension of integrating people highlights the possible investigation of social relationship between individuals.

2.3.3 Main Findings relating to Individual Diversity and Group Diversity in innovative facilities

2.3.3.1 Definitions of individual diversity and group diversity

Diversity in Innovation Facilities refers to the characteristics of an academic community consisting of groups of different researchers. The concerns of individual diversity include race, ethnicity, gender, physical abilities, sexual orientation, age, religion, social class, and many other dimensions (Harvey and Allard, 2002) and of course including discipline differences. There are two kinds of group diversity, sometimes overlapping with each other, the *systemic diversity* and the *programmatic diversity*. Systemic diversity refers to differences between institutional type, size, and control, while, programmatic diversity refers the degree level, degree area, comprehensiveness, mission, length of nominal study duration, and emphasis of the programs of the institutions (Huisman, 1995).

2.3.3.2 Measuring individual diversity and group diversity

In measuring either individual diversity or group diversity, two criteria are always essential: species richness; and evenness. In measuring individual diversity in Innovation Facilities, besides the first dimensions and the second dimensions, the third dimension as 'disciplines' differences' is crucial. On the other hand individual diversity has to be measured within a social relationship. The fourth dimension represents these social relationships. In this way individual diversity is related to group internal diversity on the third dimension, and related to group external diversity on the fourth dimension.

Despite the highly complex, the group diversity in Innovation Facilities can be measured from External diversity and internal diversity which have both vertical and horizontal divisions inside. External diversity relates to differences between

(1983) assumes an increase in differentiation: "Once created and made valuable to a group, often to an alliance of groups, academic forms persist."

33 Blau (1971) argues that: "Inasmuch as small groups that permit recurrent face-to-face social interaction are essential for social integration, the increasing size of organizations must be accompanied by differentiation into increasing numbers of sub-units. And inasmuch as specialization has compelling advantages for performance, independent of its immediate economic benefits, work tends to be subdivided in organizations as far as their size permits".

organizations in Innovation Facilities. Internal diversity relates to differences within organizations in Innovation Facilities (Blau and Schoenherr; 1971). (Stadtman and Birnbaum, 1980; 1983; Huisman, 1995)

2.3.3.3 Representing individual diversity and group diversity

The basic steps in measuring diversity in Innovation Facilities are as mentioned earlier, namely: decide an ideal sample size; draw a graph; calculate; compare differences; generate a diversity index. To represent diversity in Innovation Facilities, a graphical representation of data allows a clearer perception of the results.

Although the importance of diversity in individuals and groups is fixed, a new question emerges: how do individuals and groups (both in terms of spaces and users of these spaces) come together? Accordingly, individual diversity, group internal diversity, and group external diversity can be identified in the following tables, in which R means Richness, and E means Evenness.

Table 2.5: Table to measure individual diversity on different dimensions

Dimensions	First dimensions	Second dimensions	Third dimension (disciplines Identification)	Fourth dimension (social relationship identification)
Individual Diversity Profile	Race; gender; age; ethnicity; sexual orientation; mental & physical abilities	Religion; geographical location; profession; work profile; education; communication; first language	Disciplines differences;	Social relationship profiles
Richness Evenness	R E	R E	R E	R E

Table 2.6: Table to measure group diversity

Forms	Clusters in Innovation Facilities	Richness Evenness
Group external diversity	Classification, typology, comparison of institutions	R; E
Group internal diversity	Classification, typology, comparison of disciplines	R; E

From these tables, it is easy to see that all three kinds of diversity are actually related. In individual diversity measurements, the third dimension is actually individuals' internal group identifications, while the fourth dimension is actually individuals' external group identifications.

2.4 New networked social structure reveals that diversity occurs, grows, and evolves in clusters

In the previous chapter, the impacts of the New Environment have been studied. These impacts have further influences on the workforce and the working environment. 'The social forces and diversity concerns work to replace traditional command-and-control organizational leadership with its authoritarian ways by network leadership based upon collaboration and communication. Old rigid bureaucratic hierarchies are melting into fluid, shifting networks of relationships among employees, customers, suppliers, and allied competitors. As workforces demographics and social forces combine to change the nature of the work environment by channeling power and information to all individuals, organizations are forced to change their stances on how they handle their workforces and the diversities they contain' (Harvey and Allard, 2002). Harvey and Allard note that in this process, change efforts must be pervasive and systemic, which will involve new ways of thinking and acting. In the frameworks for organizational change, he thinks that one thread to be considered is that frameworks are multidimensional, requiring change through the organization. Study of group dynamics indicates that when groups get large, subgroups appear. It is concluded that as diversity numbers increase within an organization, the diverse are apt to form their own affinity and caucus groups (Harvey and Allard, 2002).

Harvey and Allard's conclusions suggest that the traditional hierarchical social structure will be replaced by a new-networked one, which bridges across disciplines, culture, country, race, religions, and personality. This networked society [34] is subdivided into many small groups or interacting associations which are identified as 'clusters' by M. Porter. Porter's defines the concept of "clusters" as "geographic concentrations of firms, suppliers, related industries, and specialized institutions (e.g. universities, and trade associations) that occur in a particular field in a nation, state, or city" (Porter, 1996: 199). He insists that the cluster is a prominent feature on the landscape of every advanced economy, and cluster formation is an essential ingredient of economic development. He explains the phenomenon of cluster formation as a result of both formal and informal interactions, say that, in clusters, "informal networks and formal trade associations, consortia, and other collective bodies often become necessary and appropriate" (Porter, 1996: 258).

34 Sproull and Kiesler (1991) look at the consequence of the E-revolution as a networked organization that has both technical and human components and definitions. They define a networked organization as one in which computers are connected to one another through an information transport medium that carries packets of information. Its nodes, pathways, and packets further define the networked organization. These technical components of the networked organization provide the necessary technical infrastructure to connect people but by themselves do not create the human networked organization. In this networked organization, people are connected to one another in diverse forums to exchange ideas and other resources. They draw a diagram to show how both data-based and idea-based communication can be supported on one computer network.

All these illustrate that a new-networked social structure will bring individuals and groups into ‘clusters’ in which diversity occurs, growths and evolves. To identify and measure diversity among people and spaces, the ‘clusters’ that embody them have to be further investigated. This will be done in the next chapter.

2.5 Conclusion

This chapter has examined the concept of ‘sustainability’ in relation to the development of innovative knowledge in the New Environment, and its application in designing facilities dedicated to production of new knowledge. ‘Sustainable Innovation Facilities’ (SIF) have been defined accordingly. As a necessary condition for SIF, the concept of ‘diversity’ was transferred from ecology and social science to the context of Innovation Facilities in terms of the variety of people interacting with each other. The definition, measurement and possible ways of representing ‘diversity’ in Innovation Facilities have been discussed. Diversity occurs, grows, and evolves in relation to groups formed by people interacting, which we call ‘clusters’. The next chapter will investigate the concept of ‘clusters’ as it relates to such groups as well as to the spatial organization of Innovation Facilities.

CHAPTER 3

CLUSTERS IN INNOVATION FACILITIES

Study to investigate the role of clusters in SIF

Having identified diversity people and groups in interaction as a contributing factor in the long-term production of new knowledge, we now have to identify more precisely how this requirement is related to the organization of users in groups and the physical organization of locations in built facilities. The concept of 'clusters' will be introduced as an important organizational concept for the tool to enhance the design of facilities producing innovative knowledge.

3.1 Clusters of people and Clusters of locations

As discussed in the last part of the previous chapter, diversity is a characteristic of a group formed by people who interact, which can be found occurring, growing and evolving primarily within parcels of space which we call 'clusters'. Hence it is necessary to investigate the concept of clusters and its application to Innovation Facilities. The concept of clusters will be associated with that of diversity. A cluster's formation will be identified as a necessary condition for individuals or groups to get together and interact. Consequently, the spaces used may also be organized into clusters of locations to facilitate these interactions. The design tool under study is aimed at models to represent these two kinds of cluster, and guidelines for constructing the spatial organization to facilitate the interaction of diverse researchers to encourage the long-term production of knowledge. Therefore, there are two kinds of clustering: 1) the clustering of people to interact as individuals and groups; 2) the clustering of locations to facilitate the interaction of these diverse people. It is necessary to develop adequate models to represent these two important kinds of clusters in Innovation Facilities so that diversity can be easily to be assessed and controlled in the design process.

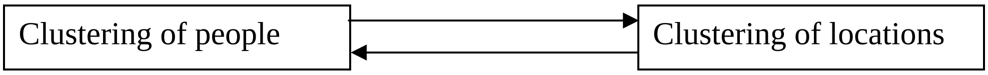

Figure 3.1: Two kinds of clusters: clusters of people and clusters of locations

3.2 Virtual clusters vs Physical clusters

In the first kind of clustering, the clustering of people, there are also two ways of interacting to form clusters of people as individuals and groups. The first is the clustering of people interacting mainly by physical spatial means; the second is clustering of people interacting mainly by virtual non-spatial means. Consequently, human interaction can be categorized into two types: Type A - face-to-face physical contact by spatial means; Type B - virtual contact by non-spatial means. Van Alstyne and Brynjolfsson (1996) have illustrated one of the negative impacts of the replacement of ‘physical places’ by virtual media, which they termed ‘Cyberbalkanization’. The advantages and importance of physical means to bring diverse researchers together are also discussed in Chapter 2. The debate about 'virtual media' versus ‘physical contact’ has gone on for the last fifty years. Similar arguments focusing on the media of the telephone and closed circuit TV were the forerunners of the current debates about email and the web. The advantage and disadvantage of both Type A and Type B interaction can be summarized in the below table.

Criterion	**Type A** (Contacts by physical means)	**Type B** (Contacts by virtual means)
Interacting **Distance**	Short	Can be as long as necessary
Cost during interacting	Low during interacting, but may be high before meeting, depending on distance between agents	Normally, higher during interacting than in Type A
Quality of interaction (Includes: details of facial expression; ease of understanding words and expressions, instant response)	High	Low
Ability to concentrate	High	Low
Reliability	High	Low
Accessibility (Whether it is easy to approach from outside)	Low	High
Frequency of use	Low	High
Speed of **Spread** of information	Low	High

Table 3.1: Type A and Type B Interaction (Physical clusters and Virtual clusters)

A fine balance combining advantages from both virtual and physical clusters is necessary, recognizing that the two are not mutually exclusive. This provides the opportunity for a generic, complementary integration of electronic media for virtual communication and a spatial physical circulation network that provides for person-to-person contact. Within such a system, electronic media link researchers with sources of knowledge all over the globe as well as with each other. The spatial structure supports face-to-face encounters between researchers within the facility. The presence of both systems, the electronic and the physical, assists the clustering of people as well as the diversity of their interaction. Electronic media are particularly useful in the clustering of a particular specialization, while physical clustering, which may operate with redundancy and low efficiency from the point of view of promoting the exchange of information between specialists in the same field, improves the diversity of interaction.

After identifying the different types of cluster, it is necessary to investigate the concept, structure and basic principles of operation of 'clusters' in relation to Innovation Facilities.

3.3 Cluster theory in planning Innovation Environment

Often, due to exogenous constraints such as proximity to fixed resources, facilities have to be geographically distributed instead of being clustered. Thus, people, who can be considered as knowledge resources, may also be distributed. However, to gain a clear understanding of the issues, this research assumes an ideal situation, in which such constraints do not exist, and so 'clusters of locations' can be formed in space.

Porter (1996) insists that clusters are a prominent feature on the landscape of every advanced economy, and cluster formation is an essential ingredient of economic development on the macro-regional scale. We will show here that important interactions in clusters can trigger innovation in facilities, and that this can be analyzed by applying the same concept at the micro-locational building complex scale. More precisely, the 'cluster' is chosen as a research devise for analyzing the 'diversity' in sustainable Innovation Facilities, because people and groups have to come together in clusters which act effectively as containers of diversity in cultivating and evolving. Not only do people have to come together to form clusters of interacting people, but also the associated spaces have to be brought together to form spatial associations to necessarily facilitate high diversity interactions among these people and groups. The design and evaluation of the spatial layouts can be implemented with the aid of the design tool.

3.3.1 The Importance of clusters of locations in sustainable innovation in the New Environment

The importance of clusters in Innovation Facilities can be explained on several levels. Classical economics usually assumes that national prosperity is created from a country's natural endowments, its labor pool, its interest rates, or the value of its currency. In the New Environment, however, this prosperity depends heavily on the capacity of its industry to **innovate** and to the existence of adaptability in maintaining innovation over the long term. The basis of competition has shifted more and more to the creation and assimilation of knowledge, not to different natural resources or to economic advantages (Porter, 1996). Ultimately, nations succeed in particular industries because their home environment is the most forward looking, dynamic, and challenging. Clustering is a prominent feature in determining the quality of the home environment. Clusters have been defined by Porter as "*geographic concentrations of firms, suppliers, related industries, and specialized institutions (e.g. Universities, and trade associations) that occur in a particular field in a nation, state, or city*" and "*a system of interconnected firms and institutions whose value as a whole is greater than the sum of its parts.*" by Porter (1996: 199). He argues that the competitiveness of locations is primarily rooted in the nature of the innovative environment[1] they offer institutions. The roots of productivity lie in the national and regional environment for competition. The nature of this type of environment is fundamentally determined by

[1] In Innovation Facilities, the sophistication and productivity with which companies compete in a location is strongly influenced by the quality of the innovative environment. This innovative environment may include fresh air, a beautiful natural environment, high efficiency of transportation facilities, advanced logistical techniques, low labor cost, a stable political situation, efficient banking facilities, and other conditions which have been identified as essential for 'environmental' and 'economic' sustainability in the study of 'sustainable development', as discussed in Chapter 2. However, the most important characteristic of an innovative environment is 'sustainable innovation' which may be considered in terms of diverse disciplines interacting to produce new knowledge sustainably over the long term. How to decide on the location of such a knowledge infrastructure and the characteristics of the associated clustering are the most important topics to be discussed in our research.

two basic conditions: **location**[2] **and physical clustering**[3] which, if appropriate, can fundamentally lift the competitiveness of company, an industry and a country (Porter, 1996).

In the New Environment, Porter explains ‘location’ and ‘clusters’ as the determinants of “long-term industry profitability” (*Sustainability*). According to Porter, to achieve this long-term industry profitability, longer-term and stronger competitive advantage is fundamental, and in this process two factors are crucial: sustained differences in resources (diversity) and location advantage (clusterability). Porter’s theory suggests that *diversity* and *clusterability* can be necessary (but not sufficient) conditions for maintaining long-term growth of new knowledge production.

As identified, knowledge production is the main driver of today’s economy. In the knowledge industry, *clustering* plays an even more important role than in traditional industries, in capturing important linkages, adding complementaries, using technological spill-over, providing skills, disseminating *information*, and promoting marketing, across technological disciplines, firms, and industries, and in fostering diversity over the long term. The *social connections* in such clusters are fundamental to competitiveness, to productivity, and, especially, to the direction and pace of the formation of new knowledge by the recombination of elements of existing knowledge. As with clustering, location also plays an even more important role than it does in traditional industries. Allocational and topological characteristics of locations limit the potential of knowledge workers from different backgrounds to meet each other and so to contribute to the sustainable production of new knowledge. In Innovation Facility, the location of clusters constrains the potential for interaction between knowledge workers from different disciplines. Thus it affects the sustainability of the production of new knowledge within the facility.

As mentioned before, in the New Environment, information and relationships that can be accessed and maintained via fax or e-mail are available to anyone. However, at the same time global sourcing and communication generate both disadvantages and

[2] The intellectual antecedents of cluster theory date back at least to Alfred Marshall who introduced a fascinating view on the externalities of specialized industrial locations in his famous ‘Principles of Economics’ (originally published in 1890).

[3] Porter identifies a Diamond Structure to explain how clustering works, from which he develops a new theory of the competitiveness of nations, states, and their relationship with the geographic regions.

advantages. Moreover, sourcing from a distant location is generally a second-best solution compared to accessing a competitive local cluster, in terms of both total productivity and innovation. The importance of physical clusters is clear, and its advantage cannot be replaced by replacement of virtual distant means. As a result, the enduring competitive advantages (sustainable competitive advantages) in a global economy are usually local, arising from concentrations of highly specialized skills and knowledge, institutions, related businesses, competitors, and sophisticated customers in a particular nation or region. Proximity in geographic, cultural, and institutional terms allows ready access, special relationships, better information, powerful incentives, and other advantages in productivity and productivity growth that are difficult to tap from a distance (by E-means). Standard inputs, information, and technologies are readily available via globalization, while the more advanced dimensions of competition remain geographically bounded. Both *Clusters* and *Location* thus do matter in the New Environment, albeit in different ways at the start of the twenty-first century to those applying in earlier decades. Deciding on locations and the relationship between locations (the structure in a cluster of locations) are hence a central task in designing Innovation Facilities for the sustainable production of new knowledge.

3.3.2 Advantages of physical face-to-face interaction in a cluster

How can clusters affect competitive advantage in Innovation Facilities? Clusters effectively work in three broad ways: first, by increasing the productivity of constituent groups; second, by increasing their capacity for innovation and thus for productivity growth; and third by stimulating the formation of new knowledge that supports innovation and expands the cluster. All these ways, however, rely heavily on face-to-face physical interaction and personal relationships within the cluster. As noted by Porter (1996): "*Each of the three broad influences of clusters on competition depends to some extent on personal relationships, face-to-face communication, and interaction among networks of individuals and institutions*". The existence of a cluster makes such relationships more likely to develop and also more likely to be effective once established in a physical place in Innovation Facilities. Only with all these three basic necessary conditions (*personal relationships, face-to-face communication, and interaction among networks of individuals and institutions*) can a cluster work properly to guarantee those three broad ways in the long term. Porter further points out that: "*Formal and informal organizing mechanisms and cultural norms often play* *a role in the development and functioning of clusters”*. In our research the information flows via these informal or formal networks will be represented in some special schematic models which describe social relationships between knowledge workers. The advantages of physical clustering in fostering sustainable new knowledge production in Innovation Facilities can be summarized as the following points.

Advantage 1: Physical clusters increase knowledge productivity in Innovation Facilities

There are five reasons which explain why clustering can stimulate new knowledge generation and hence increase knowledge productivity in Innovation Facilities. Clusters help provide 1) better access to specialized inputs and researchers; 2) better access to information; 3) better complementarities for the knowledge industries; 4) better access to institutions and knowledge products; 5) stronger incentives and better performance measurement.

Advantage 2: Physical clusters can combine both competition and cooperation efficiently and effectively

Clusters clearly represent a combination of competition and cooperation. Competition and cooperation can coexist because they occur in different dimensions between different players; cooperation in some dimensions aids successful competition in others. In particular, competition may work on, say, the horizontal level inside the cluster; therefore the best knowledge provider can be selected on that level via competition. On the other hand, cooperation works in a vertical manner inside the cluster; therefore the best knowledge production-sell-service chain can be optimized in a cluster to give the lowest cost and in the highest efficiency.

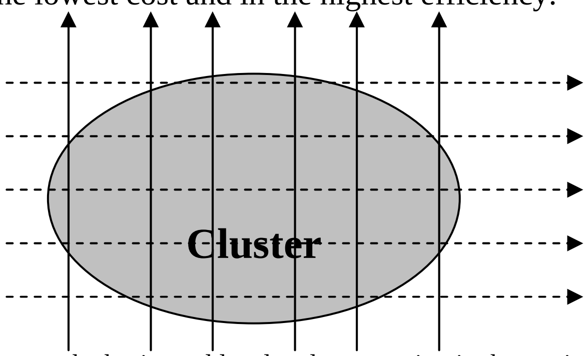

Figure 3.2: Competition on the horizontal level and cooperation in the vertical direction in a cluster, leading to the lowest price and highest efficiency. (Solid arrows represent cooperation; dotted arrows represent competition)

Advantage 3: ‘Social glue’ binds members together in physical clusters

Social glue binds researchers in clusters together in Innovation Facilities, contributing to the created affix value in the process. Many of the competitive advantages of clusters depend on the free *flow of information between divers disciplines*, the discovery of value-adding exchanges or transactions, the willingness to align agendas and to work across disciplines, and strong motivation for improvement. Relationships, networks and a sense of common academic interest undergird these activities. The social structure of clusters thus takes on a central importance, which will be investigated and represented in models in later chapters.

Advantage 4: Physical clusters benefit diversity and vice versa

As concluded above, clusters provide containers in which diversity of interacting groups can occur and evolve. From another viewpoint, diversity can also benefit clusters. Diversity plays a vital role in gaining competitive advantage from outside the cluster (whatever relying on *external diversity* or *internal diversity*). As a result, in a diverse cluster, the net access to specialized skills, services, technology, and information often increases. Any such increase in competition promotes cluster benefits in terms of improved productivity, flexibility, and innovation. In such a cluster, conditions can be improved by enhancing the supply of appropriately trained personnel, upgrading the quality and appropriateness of local university research activities, the creation of a specialized physical infrastructure, and the supply of cluster's specific information. The proposed design tool will help in the creation of such a specialized physical infrastructure enhancing interaction between diversity individuals and groups in clusters.

3.3.3 The possibility of using the concept of clusters in our research: from Macro-Cluster to Micro-Cluster

As concluded above, clusters are the containers in which diversity can occur and evolve. *Cluster of locations* determine competitive advantage in new knowledge production. To maintain such an advantage over the long term, potential interaction among diverse agents in clusters is necessary. Such interaction of diverse researchers can maintain sustainable innovation over the long term. According to Porter (1996), all the knowledge productivity advantages of clusters in Innovation Facilities depend on 4 key necessary conditions (necessary, but not sufficient[4]):

[4] There are many other conditions which influence the formation of effective clusters. For instance, an effective cluster structure exhibits four kinds of balance: 1) balance between competition and

1. Physical proximity[5]; (this will be investigated as *topological architectural constraints*);

2. Face-to-face contact; (this is identified as *physical interaction*);

3. Close and ongoing relationships; (this will be represented in specific models to represent *social relationships* that determine the flow of diverse information);

4. “Insider” access to information. (This can be understood as *accessibility*).

Porter (1996) insists that clusters arise in many types of industries in both larger and smaller fields clusters vary in size, breadth, and state of development. This highlights the possible extended application of the concept from macro-regional scale to the micro-locational scale of building complexes. Before applying a transfer between the two scales, a basic comparative study between Macro-clusters and Micro-clusters is necessary, which will identify some of the similarities and differences between them. We consequently examines whether the 4 basic conditions for macro-regional clusters also apply in micro-locational clusters. These are analyzed in a table below:

	Macro-Cluster	**Micro-Cluster**
Scale	Macro	Micro
Physical accessibility	Possible but expensive	Possible and cheaper (but under specific physical constraints)
Face-to-face contact	Difficult and expensive	Frequent and cheaper
Close and ongoing relationships	Yes (but mostly by virtual means)	Yes (mostly by physical means)
“Insider” access to information	Yes	Yes

Table 3.2: A comparison between macro-regional clusters and micro-locational clusters

We find that most of those conditions which apply at the macro- level also apply to

collaboration; 2) balance between privacy and community; 3) balance between centralization and decentralization; and 4) balance between homogeneity and heterogeneity.

[5] These advantages of geographic proximity in a cluster may be summarized as follows: 1) transaction costs are reduced; 2) the creation and flow of information improves; 3) local institutions respond more readily to a cluster’s specialized needs; 4) peer pressure and competitive pressure are keenly felt. Therefore, a cluster usually and naturally originates and grows up in a region which has these advantages to attract more members to join the cluster. Regions without these advantages will generally be less able to form effective clusters.

the micro-locational cluster. In later chapters the concept of clusters will be employed on two aspects: clusters of knowledge workers and cluster of locations in which these knowledge workers interact. In the process, the network model representing relationships and locations will be helpful in understanding the structure of these kinds of clusters. The first type of cluster, clusters of people, can be at the level of both the Macro- and the Micro- cluster; however, the second type, clusters of locations, is mainly relevant to Micro-Clusters. In a micro-locational building complex, all the above conditions seem to be satisfied. But it is important to keep in mind that these conditions can be fixed only on the basis of certain pre-conditions, and these form the main differences between the macro-regional cluster and the micro-locational cluster. These pre-conditions are as follows:

1. Physical accessibility in building complexes is constrained by their spatial arrangement;
2. Face-to-face contact in a macro-regional cluster is possible but difficult and expensive; however in a micro-locational cluster, it is very possible and cheap;
3. In a macro-regional cluster, close and ongoing relationships tend to be involving interaction mainly by virtual means; however, in a micro-locational cluster, interaction can be by physical means.

In short, the conclusion is that Porter's theory of clusters on a macro-regional scale can be used also on a micro-locational scale. However, when the theory is transferred, a study of the constraints of topology is necessary, since topology is a more effective constraint at the micro level. This topological constraint will be discussed in later chapters. In the next section, we will briefly discuss the distance constraint in both social clusters and locational clusters on basis of the theory of cluster analysis.

3.4 Cluster analysis to determine the distance in a cluster: Euclidean distance and Non-Euclidean distance

Cluster Analysis (CA) is a classification method that is used to arrange a set of objects into clusters. The aim is to establish a set of clusters such that cases within a cluster are more similar to each other than they are to cases in other clusters. Cluster Analysis provides a scientific way in classifying objects in our world. It has wide application in varying disciplines including biology, ecology, evolution science, economics, sociology, engineering, management, aetiology, archaeology, psychiatry, and astronomy. The techniques used in CA can cover: visualizing clusters, measurement of proximity, hierarchical clustering, and optimization clustering (Everitt, Landau and Leese, 2001).

In this study, we will focus on the distance measurement in CA, because the distance between disciplines and between locations plays a vital role in determining the identification of diversity.

There are different ways to measure a distance. These include Euclidean measurement (can be measured with a 'ruler') and non-Euclidean measurement (cannot be measured with a 'ruler'). For example, in terms of road distance (a Euclidean distance) the city of York in the UK is closer to Manchester than Canterbury. However, if the ‘distance’ is measured in terms of the cities' historical and social characteristics, York is closer to Canterbury since both are ancient cathedral cities. It is also necessary to take account of the type of data since each has its own set of distance measures. Generally there are 3 broad classes: interval; count; binary. In our first model (see chapter 6 ‘Sociogram’), non-Euclidean measurement will be employed. However in our second model (see chapter 7 ‘Archigraph’) Euclidean measurement shall be kept in mind, because in measuring social relationships, physical Euclidean distance is not the key fact in determining a relationship. For instance, however far away your father is from you, he is still your father. However, the location profile in an architectural plan is primarily determined by Euclidean distance. Although in an Archigraph, locations which share common activities still can be classified in one cluster, the physical distance between locations cannot be neglected. However, the central issue in this research is topological constraint instead of time-distance constraint or space-time model which will be very helpful for the extension of this research in future.

CA classifies a set of observations into two or more mutually exclusive unknown groups based on combinations of interval variables. The purpose of CA in our research is to develop a system of organizing observations, usually people or locations, into groups where members of a group share properties in common. It is cognitively easier for people to predict behavior or properties of people or objects based on group membership, since all members share similar properties. In the chapter of ‘Sociogram’, a social cluster is identified when most members in this cluster share some similar academic interest and are involved in cooperative academic activities.

In Innovation Facilities, a ‘cluster’ will be analyzed in its simplest way. As mentioned, there are two kinds of cluster: clusters of knowledge producers, and clusters of locations. To identify members of a cluster around one node, we will consider as valid members of the cluster only those nodes which are connected with this node within a distance of one or two node connections, because whether in a Euclidean system or a non-Euclidean system, when distance increases, the possibility of interaction declines drastically. The conclusion is that the greater the distance, the lower the accessibility, cohesiveness[6] and clusterability[7], and as a result, the harder it is to form a cluster (see Figure 3.3).

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[6] Cohesion is the soul of ‘Clustering’. Without group cohesion, it is impossible to construct a cluster. With the concept of group cohesion, it is easy to measure the potential of a group to form a cluster. In the theory of Wasserman, Stanley and Faust (1994), clusters are explained by a similar concept of ‘Cohesive Subgroups’: “Cohesive subgroups are subsets of actors among whom there are relatively strong, direct, intense, frequent, or positive ties.” Therefore, if a group of nodes has a higher coefficient of cohesion than the others, then this group can be identified as a ‘cluster’. Vacha et al (1979) have described group cohesion in education research as: "...the attraction structure of the classroom and involves not only individual friendships but also the attractiveness of the whole group for individual students”. Student cohesiveness can either support or undermine educational goals depending on the impact of other group processes in the classroom. (Vacha et al ,1979)

According to Diaz-Guilera (2003), the clustering coefficient of a node is calculated by the equation (left); and the Clustering coefficient of the network is calculated by another equation (right):

$$C_i = \frac{E_i}{k_i\,(k_i - 1)/2} \qquad ; \; C = \frac{1}{N}\sum_{i=1}^{N} C_i$$

Diaz-Guilera (2003) argues that the clustering coefficient is much larger than it is in an equivalent random network. Szabo, Alava and Kertesz (2004) suggest an equation to calculate the Clustering Coefficient. The local clustering coefficient Ci of a node I has been introduced to express the connectedness of the node’s neighbors with each other:

Ci=the number of direct links between neighbors of I / number of all such possible links.

Newman (2004) suggests a different equation: C = 3 x Number of triangles on the graph / number of connected triples of vertices.

The coefficient of cohesion can also be calculated directly from Sociometric data used to diagnose "positive nomination" data. All of the data necessary are contained in the Sociogram. To calculate the coefficient of cohesion, simply count the number of mutual positive choices made by all of the researchers, the total number of positive choices made by all of the researchers, and the number of researchers who completed the survey. The coefficient of cohesion can then be calculated using these totals according to the following formula:

C = Mq/Up Where:

- C = the coefficient of cohesion.
- M = the total number of mutual positive choices made by the students.

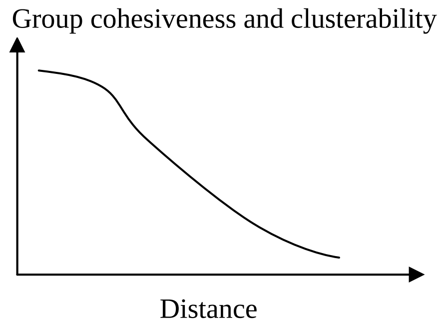


Figure 3.3: Relationship between distance and group cohesiveness and clusterability

This is not difficult to understand. In a non-Euclidean system like a social relationship, when a close friend (B) introduces you (A) to another of his close friends (C), there are only two connections between A and C, and A and C may readily become trusted friends. However, when C introduces A to his close friend D's close friend E, the distance between A and E is 4 connections, and A and E are less likely to become closes friend than A and C, since a longer distance has to be passed. It is the same a Euclidean system like architectural space. When one location is too distant from another, attempts to organize common activity between them decline sharply. This is called a 'time-distance' constraint in architecture, or in other words, a 'time-space model' as identified by Hägerstrand around forty years ago.

Therefore in Innovation Facilities, there are two criteria to identify a cluster:

1. The members of the cluster have to share some similar academic interest and cooperative activities;

2. All the members have to be within 1 or 2 connections' distance; members at a greater distance cannot be taken into account.

· U = the number of unreciprocated positive choices (the total number of positive choices minus the number of mutual choices (M).

· p = d/(N-1) where d is the number of positive choices allowed and N is the number of students completing the survey. All these equations can be used in a Sociogram to decide whether a group of researchers can be identified as a cluster.

[7] In Graph Theory, a signed graph is clusterable, or exhibits clustering if one can partition the nodes of the graph into a finite number of subsets such that each positive line joins two nodes in the same subset and each negative line joins two nodes in different subsets. The subsets derived from the clustering are called clusters.

3.5 Diversity within a Cluster: Diversimilarity, a subtle balance between Homogeneity and Heterogeneity

So far, both the concept of 'diversity' and the concept of 'clusters' have been studied. Diversity in interaction is an important necessary condition for sustainable innovation, and clusters provides an ideal vehicle for diversity to occur and evolve.

However, diversity in clusters is more complex than may be imagined, since it has to be observed in a dynamic dialectic. On one hand, the greater the homogeneity in a group, the easier it is to form a cluster, but the greater the possibility of decreasing diverse thinking[8]. On the other hand, the greater the heterogeneity in a group, the harder it is to form a cluster, but the greater the possibility to increase diversity and creative thinking[9]. It is also certain that, just having diversity does not by itself guarantee qualitative social and creative activity; diversity is a necessary condition but not a sufficient one. In some cases, too much diversity can be counterproductive, just as too much conformity can be stifling (Allard, 2002). Bringing people from different backgrounds together in a diverse interacting cluster is actually a static point of view. Dynamically, there needs to be a fine tuning mechanism to maintain an adaptive balance between homogeneity and heterogeneity[10] so that high potential of both clusterability and diversity can be maintained to support sustainable knowledge

[8] It is also concluded that, since group cohesiveness is directly related to the degree of homogeneity, and group thinking only takes place in highly cohesive groups, the occurrence of cultural diversity in groups should reduce the probability of cohesiveness. (Shaw, 1981; McGrath, 1984; Janis, Irving, 1972). Group cohesiveness and a high degrees of homogeneity will help in forming of a cluster; however it will reduce the potential for creativity.

[9] Since the 1960s, several studies in the University of Michigan had revealed that heterogeneous groups produced better quality solutions to assigned problems than homogeneous groups. Later the same conclusion was arrived at indirectly by research on the "groupthink" phenomenon, which indicated that the absence of critical thinking in groups was caused partly by excessive preoccupation with maintaining cohesiveness.

[10] Heterogeneity and Homogeneity (or Differentiation and Dedifferentiation) can be understood best in the tension of power relationships between interest groups (Clark, 1978, 1983; Meek, 1991; Rhoades, 1983, 1990). In addition, the characteristics of the academic profession (Jencks and Riesman, 1968; Rhoades, 1983, 1990; Riesman, 1956), the policies and steering approach of the government (Maassen and Potman, 1990ab; Meek, 1991; Rhoades, 1983, 1990) and the reaction of institutions influence differentiation and dedifferentiation. We will measure academic profession in terms of the difference between disciplines in Sustainable Innovation Facilities. The norms and values of the academic profession are thought to be inhibiting factors for differentiation of roles and functions at the higher education system level. Competition between institutions may stimulate differentiation by forcing institutions to look for their own niche in the market place (see also Birnbaum, 1983).

production over the long term. To form a cluster with higher diversity over the long term it is hence necessary to seek a subtle balance between homogeneity and heterogeneity.

As a consequence, performance of a cluster is best when there is neither excessive diversity nor excessive homogeneity. Shepard summed this up as: "*Similarity is an aid to developing cohesion; cohesion in turn, is related to the success of a group. Homogeneity, however, can be detrimental if it results in the absence of stimulation. If all members are alike, they may have little to talk about, they may compete with each other, or they may all commit the same mistake. Variety is the spice of life in a group, so long as there is a basic core of similarity*" (Shepard, 1964). In addition, all members need to share some common values and norms in order to promote coherent actions towards organizational goals. Therefore, the need for heterogeneity, to encourage problem solving and innovation, must be balanced by the need for organizational coherence and unity of action. In short, diversity in workforces creates competitive advantage through better decisions via both homogeneous and heterogeneous characteristics of the group. To form a diverse clusters for maintaining sustainable knowledge production over the long term, there is perhaps a need for both homogeneous and heterogeneous interaction at different phases of development, although in our research the emphasis is on diversity. An adaptive system is thus suggested to pursue the best balance between homogeneity and heterogeneity, a compromise which has been termed diversimilarity[11].

[11] Ofori-Dankwa, and Julian propose the new concept of "diversimilarity" to overcome the contradiction between homogeneous and heterogeneous, which look at workplace diversity issues and simultaneously considers the differences and the similarities between individuals, and both are regarded to be equally essential. (Ofori-Dankwa, and Julian, 2002; Loden and Rosener, 1991; Ofori-Dankwa, 1996; Ofori-Dankwa, and Bonner, 1998). Diversimilarity is based on the idea that diversity can be better managed if people are simultaneously conscious of the differences and similarities that co-exist between them. Ofori-Dankwa, and Bonner (1998) use five principles to summarize diversimilarity. They are: 1) creativity and adversity in diversity; 2) conformity and compatibility in similarity; 3) diversity within diversity; 4) similarity across diversity; and 5) managing diversity by managing diversimilarity.

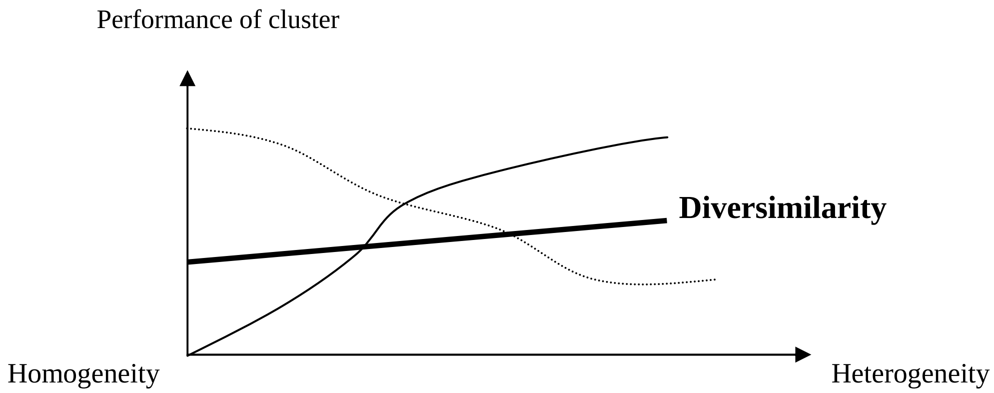


Figure 3.4: Relationship between Heterogeneity, Homogeneity, Clusterability, and Creativity (The thin line represents creativity, the dotted line represents clusterability and group cohesiveness, and the bold line is 'diversimilarity')

The concept of diversimilarity is important in Innovation Facilities to maintain long-term new knowledge production in an evolving balance-seeking process through adaptation. In an Innovation Facility, the similar concept of diversimilarity is that it is better if both heterogeneity and homogeneity coexist. On the one hand the agents in the cluster should share some common characteristics and become familiar with each other in order to maintain a stable cluster, while on the other hand they should remain as different as possible is spite of the tendency to become similar. A possible solution is to continually exchange members between different social clusters so that diversimilarity can be achieved. The topological constraints in an architectural plan seem to provide such opportunities to exchange members between different social clusters. Either social clusters or locational clusters thus need to be represented in appropriate models. The design tool needs to provide a dynamic mechanism to control dynamic intellectual diversity in clusters in order to promote long-term creativity in Innovation Facilities.

3.6 Conclusion

In this chapter, we have discussed the concept of 'clusters'. We defined cluster diversity as the characteristic of the variety of people interacting within a cluster. The variety of groups depends on their heterogeneity of knowledge. The diversity of a cluster therefore depends on the interactions that take place between groups within and between the clusters that are different in certain respects. We will later show how this cluster diversity can be derived and through what model it can be estimated. The necessary conditions for maintaining the advantage of diversity in clusters in order to sustain the long-term production of new knowledge producing have been identified. Among these necessary conditions, two are crucial: physical face-to-face interaction in *clusters of nearby locations*; close and ongoing *clusters of people glued together by social relationships* to facilitate internal access to information.

Therefore, in the next steps of the research, there need to be two models to effectively represent, first, clusters of physical locations, and second, clusters of people who interact within these cluster locations.

We have now to investigate what are the physical conditions that constrain the diversity in potential clusters of interacting groups or individuals in Innovation Facilities? What are the conditions that constrain the potential of meeting? Given the complexity of the problem, we will introduce a case study to assist in addressing these issues.

CHAPTER 4

USE OF A CASE STUDY TO IDENTIFY ISSUES RELATING TO INNOVATION FACILITIES

The campus of TU Delft

The previous chapters examined the concepts of 'diversity' and 'clusters' in relation to Innovation Facilities. This chapter discusses a case study carried out on the campus of TU Delft to illustrate how diversity and cluster formation relate to the physical spatial organization of a facility. A number of interviews were undertaken and some basic data were collected. The data were analyzed and some conclusions were drawn concerning the main issue of how architectural design constrains the diversity of people interacting on the campus. The consequences of these findings are analyzed, pointing to the role of the physical environment in enhancing innovation and suggesting criteria that the design tool should meet in order to be effective.

4.1 Introduction

As mentioned before, Innovation Facilities are facilities that produce new knowledge, which include universities, science parks, and offices. Chapters 2 and 3 identified the interaction of diverse researchers in clusters as a crucial requirement for sustainable innovation. The task here is to present a case study to investigate: do current Innovation Facilities provide the necessary potential interaction of diverse researchers in clusters, or not? And what circumstances and conditions allow or prevent these potentials?

This case study provides a preliminary observation of the problems in a typical Innovation Facility --- Delft University of Technology (TUD). Although the case study mainly focused on the problems in a university campus, the problems identified are widely mirrored in other Innovation Facilities. This *preliminary case* (Yin 1993, 1994; Hamel et al. 1993) will mainly serve as a *heuristic device*. The problems identified in the case study will be examined further in depth and developed taking account of new changes in the New Environment.

Prior to describing the case study itself, this chapter will first introduce some basic methodological aspects related to the use of case studies in general and to the reasons for choosing this approach. We will first review the advanced methods of undertaking case studies, take a first look at the potential problems in this case study, and review the methods to be applied to the analysis. Secondly, we will define targets, objectives, and the process to be applied in the case study. Thirdly, the chapter will describe the collection of the necessary data on fields and organize interviews, which serve as the basis for this case study. Basic information of the case will be introduced generally. Fourthly, it will present an analysis of these data aimed at identifying the main issues in contemporary Innovation Facilities. Finally, it will describe further analysis of these issues to identify potential factors causing these problems. Both preliminary and in-depth analyses will help in defining the issues in Innovation Facilities as well as in the construction for a design tool for Innovation Facilities.

4.2 Case Study of TU Delft

4.2.1 Why use a case study method in this research?

The case study method was originally created by Hippocrates[1]. Since Hippocrates, the case study method has been used for many years across a variety of disciplines[2]. The method is widely recognized as way to seek to identify a class of phenomena through

1 The "Father of Medicine", Hippocrates (460 BC -377 BC) is the Greek physician who advocated the importance of the accumulation of 'cases' in medicine. These case studies of the human body played an important role both in forming a diagnosis and in studying kinds of disease. This was to the way for scientific diagnoses and free medicine from superstitions and illness from being seen as merely dependent on the will of the gods.

2 These disciplines cover sociology, economics, anthropology, politics, management and even architecture. Social scientists, in particular, have made wide use of this qualitative research method to examine contemporary real-life situations and provide the basis for the application of ideas and extension of methods. Frederic Le Play, Bronislaw Malinowski, and members of the Chicago School, French or Anglo-Saxon schools are typical schools of case study method.

Case study has been a usual method of study in Harvard Business School. Adelman and Walsham accepted the case study method's key role in the development and evaluation of information systems (Adelman, 1991; Walsham, 1993).

Jane Jacobs (1961) successfully used the method of case study to generalize theory in urban planning while analyzing the great American cities. Researches have involved a ournalistic report on the design and constructions of the Worldwide Plaza in New York (Sabbaugh, 1989); a study about architectural firms in the USA and Turkey (Akin, 1993; 1996); exploration of design process (Shoshkes, 1990); a pedagogical collection of cases (Pollalis, 1993); the design and construction of the Centre Pompidou and the Phillips Pavilion at the 1958 Brussels World fair (Silver, 1994; Treib, 1996); Moreover, Donald Schon produced fruitful examples of case studies. The case study approach has become a basic method in Design Knowledge Systems Research Centre, TU Delft, Netherlands (Fang, 1993; Yu Li, 1994; Scriver, 1994; Jeng, 1995; Heintz, 1999).

a scrupulous examination of particular instances. It is thought to excel at bringing us to an understanding of a complex issues or objects that cannot be easily dissected into parts and for which no explanatory models or theories exist. (Chapter 5 illustrates more fully the absence or inadequacy of existing theories.) As with all highly complex problems, it is hard to apply pure logical analysis. Case studies emphasize a detailed contextual analysis of a limited number of events or conditions and their relationships. Case study method can extend experience or add strength to what is already known through previous research. These are the reasons for deciding to use the case study method to investigate current Innovation Facilities.

4.2.2 Reasons for selecting TU Delft for the Case Study

1) Context

TU Delft is located in one of the world's most highly developed countries, with a high reputation regarding innovation and its economy[3]. TU Delft is becoming a leading locomotive in this development.

2) Modern and Leading

Unlike most other European counterparts, TU Delft is quite young. Since it was founded in 1842, the University has frequently updated its system according to most advanced standards. Both the national network and international collaborative network shape TU Delft into an undoubted modern and leading University in the world.

3) Typical

TU Delft[4] is typical Dutch university of technology but also typical in the European context. It is located in a typical, quiet Dutch town with typical Dutch houses and canals. As a typical technology university it covers most technologies domains including architecture, industrial design, civil engineering, electrical engineering, aerospace engineering, geosciences, life science and engineering, marine technology, chemical engineering, applied physics, computer science, applied mathematics, mechanical engineering, and other advanced technologies.

3 The Netherlands has a long history of world trade, and very stable political and macroeconomic environments. It boasts a highly developed financial sector and a well-educated labor force. The Netherlands is one of the top dozen trading countries in the world and it is ranked 13th in GNP. In the context of international trade, the Netherlands is a key center within the global business network. In the worldwide tide of the Knowledge Economy, the Dutch economy is increasingly defined as a 'Knowledge Based Economy'. Building a knowledge-driven country has thus become the country's chief task in the new century.

4 See http://www.tudelft.nl to collect the most updated statistical figures and information.

4) Innovative

Through fundamental and applied research and educational programs, TU Delft prepares the engineers of tomorrow, advancing the state of technology further on behalf of society. TU Delft takes knowledge seriously and applies it practically in many innovative fields covering: water and soil, architecture and design, environmental technology, information technology and innovative transport systems. Statistics supporting TU Delft position as an innovative university can be found later part in this chapter.

5) Highly Accessible

The Design Knowledge System Research Centre is located on the campus of TU Delft. The proximity to other parts of the university makes it easy to collect any relevant data at any time for this research, and to interview people as required.

4.2.3 General principles followed in designing the case study

The framework chosen for performing the collection of data and subsequent analysis for the case study mainly follows the method proposed by Yin (1994) [5].

The preferred features of case study research included: 1) a preference for qualitative data - understood simply as the analysis of words and images rather than numbers; 2) a preference for naturally occurring data - observation rather than experiment, unstructured rather than structured interviews; 3) a preference for meanings rather than behaviors - attempting to document the world from the point of view of the people studied.

It should be pointed out that the aim of the case study was not to test any hypothesis or to draw conclusions. Its function was rather heuristic, to identify the adequacy

5 The elements required in a case study are a pre-investigation, data collection, analysis, preliminary and in-depth investigation, and conclusion. There are various methods of using case studies. The case-study method is used here as a research tool to explore issues instead of being used as only a supplementary means to verify an issue. Yin insists that a case study allows an investigation to retain the holistic and meaningful characteristics of real-life events. The essence of a case study, the central tendency among all types of case study, is that it tries to enlighten a decision or set of decisions: why they were taken, how they were implemented, and with what result (Schramm, 1971; Yin, 1994). Yin (1994: 13) thus defines a case study as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”.

Yin simplifies the process of a case-study into 3 steps: designing the case-study; collecting the data; and analyzing the data. A ‘blueprint’ of a case study can be described as dealing with four issues: 1) What questions should be asked; 2) What data are relevant; 3) What data should be collected; and 4) How the results should be analyzed. (see Yin, 1994; Borum, 1991; Philliber, Schwab, and Samsloss, 1980). Yin (1994: 20) also formulates five important components of research designed on the basis of case studies: 1) a study’s questions; 2) its propositions, if any; 3) its units of analysis; 4) the logic linking the data to the propositions, and 5) the criteria for interpreting the findings.

criteria for the design tool under development. More precisely it was to highlight aspects of the built environment that have relevance to the problem of designing facilities for the sustainable production of new knowledge.

4.2.4 Design of the TU Delft case study

Having looked at the general principles we are now looking at the specific requirements in our study. In our study of Innovation Facilities, the case study will be used to investigate whether the potential meeting between diverse agents in clusters can frequently occur in current Innovation Facilities? The collected data will include a map of the campus and a typical daily schedule of agents from several different faculties. In analyzing the results, the study will focus on whether or not they can potentially meet each other. What are the conditions which promote or hinder the possibility of them meeting? The key unit for analysis in this case study is the number of times they meet. The logical link between the data and the propositions is: if the chance of their meeting is too low, then it is not easy to form a diversity interacting cluster, which has been identified in previous chapters as a crucial requirement for sustainable innovation. The study then will investigate in-depth what factors cause the insufficiency. These factors will be interpreted into basic criteria for the proposed design tool in order to remedy the insufficiency.

Six specific steps for a case study are proposed as follows: 1) determine and define the research questions; 2) select the cases for study and determine the techniques for data gathering and analysis; 3) prepare to collect the data; 4) collect data in the field; 5) evaluate and analyze the data; 6) prepare the report. These will also form the basic steps in performing the case study on TU Delft.

4.3 Preparation for the Case Study and the Collection of Data

4.3.1 Preliminary investigation for the case study

Before commencing the case study proper, some preliminary investigations are necessary. The first is to confirm the identity of TU Delft as a research institution, because our research interest is to supervise sustainable innovation in terms of research studies. The second is to collect information and documents relating to the development of multiple-disciplines in TU Delft and its efforts in this direction.

Consequently for the case study an interview was conducted with Mr. de Boer, a senior Policy Advisor of the university. He outlined the progress of the university in recent years relating to multiple-disciplinary developments. The mains questions asked, and the relevant information obtained are listed below.

1. To what extent can TU Delft be described as a research institution instead of a pure teaching university? [6]

To investigate whether TU Delft is a research institute, and whether the research function can be improved, it needs to be investigated with regard to three aspects:

1) Whether the *number of staff members* who are doing research, is greater than the number teaching;

2) Whether the *input budget* for research is higher than that for teaching;

3) Whether the *research output* is the main output of the university;

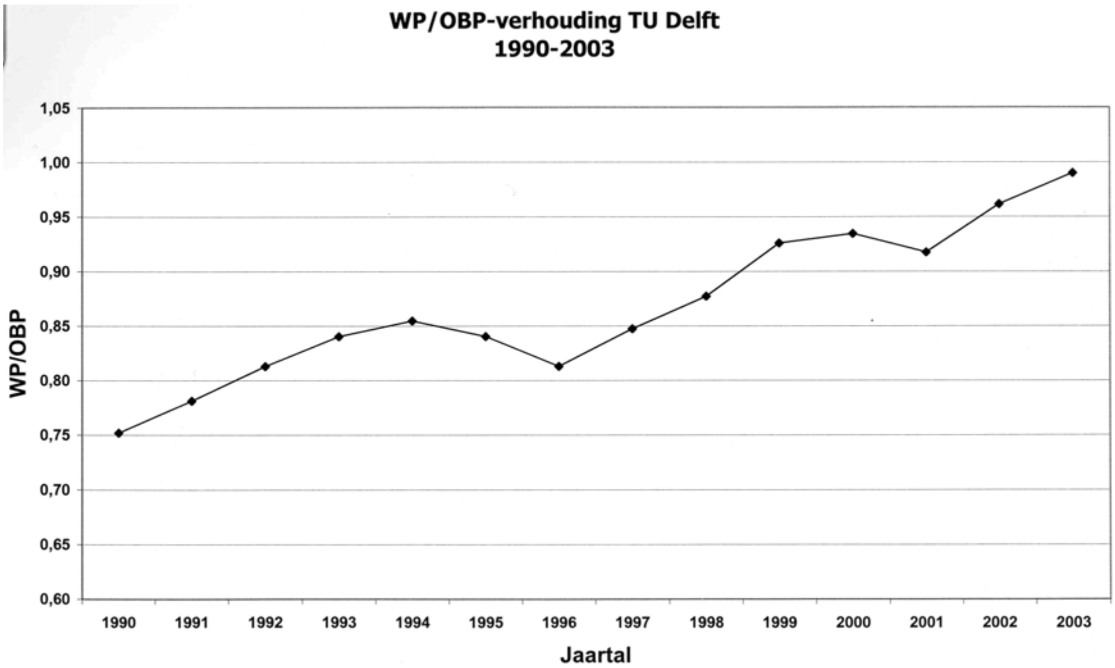


Figure 4.1: WP/OBP percentages over years. (Source: Office of Strategic Affairs in TU Delft: de Boer, 2004) Verhouding: proportion Jaartal: year

WP/OBP is the ratio of research and teaching staff to support staff in TU Delft. From Figure 4.1, which shows the WP/OBP ratio over a number of years, it is easy to see that from 1990 to 2003, this ratio increased drastically, which indicates that more and more tasks in the university were research and teaching instead of administrative and support tasks. For example, in 2002, WP/OBP was 0.96, but in 2003, it was 0.99. Even these teaching staff are inevitably involved in research. As mentioned at the start

6 In the Dutch education system, there are two main kinds of universities. The first is called ‘Universaliteit’ whose main function is research. The second is called ‘Hogeschool’ whose main function is professional education. TU Delft is one of the leading universities of the ‘Universaliteit’ kind.

of this dissertation, one important change in the New Environment is the blurring between research and teaching, and as a result many teaching tasks may eventually be seen as research as well.

According to the document ‘TU Delft in Beeld 2003-2004’, in 2003 the number of persons in the university doing research was 1145 (taking into account only Professors, Associate Professors, and PhD students), which is 1145/2309=49% of all employees of the university. Therefore half of the employees were directly involved in research instead of teaching. The conclusion can thus be drawn that in TU Delft, the number of staff who are doing research, is bigger than the number who are teaching.

onderzoek totaal

toewijzing voor		BK	CiTG	EWI	IO	IRI	LR	OTB	TBM	TNW	WbMT	totaal
	onderwijs	23,2%	14,9%	12,3%	12,1%	0,0%	9,6%	0,0%	7,9%	8,5%	11,4%	**100%**
	onderzoek	8,0%	13,1%	16,5%	5,2%	7,5%	7,6%	2,6%	5,3%	22,5%	11,8%	**100%**
	totaal	14,7%	13,9%	14,7%	8,2%	4,2%	8,5%	1,4%	6,4%	16,4%	11,6%	**100%**
onderzoek: onderwijs		0,34	0,87	1,35	0,43		0,79		0,67	2,64	1,03	**1,24**

TU Delft Financiën & Control
Concern Business Control

Figure 4.2: Proposed Research-Teaching ratio in different faculties of TU Delft. (Source: Financiele Kaderstelling 2005-2008: de Boer, 2004) toewijzing voor: allocation for onderwijs: education onderzoek: research

The R/T ratio is the ratio between funds for research and funds for teaching. If R/T is greater than 1, this means that more money has been put into doing research than teaching. It is found that although the ratio varies between faculties (in BK ‘Faculty of Architecture’, the least research is done; in TNW ‘Faculty of Applied Science’, the most research is done), in TU Delft as a whole, the R/T ratio is 1.24 in the proposal for 2005, which means more input money will be put in research in TU Delft in 2005.

Figure 4.3 is the detailed budget of TU Delft for 2005. From this it may be seen that the percentage of budget allocated to research is 143.4/342=42%, while that allocated to teaching is 109/342=32%, indicating that a significantly greater proportion of the input budget is applied to research than to teaching.

Het allocatiesysteem heeft drie hoofdcomponenten, die elk zijn onderverdeeld in componenten en (sub)boxen; de bedragen zijn in miljoenen euro's en hebben betrekking op het jaar 2005:

NB nog actualiseren			Bedrag	bedrag	bedrag	bedrag cum.	%	% cum.
Instellingscomponent			86,6					
	Centrale voorzieningen				59,8	59,8	17,5	17,5
	TU-programma's				26,2	86,0	7,7	25,1
	Oper.verplichtingen				0,7	86,6	0,2	25,3
Onderwijscomponent			109,0					
	Strategie				5,5	92,1	1,6	26,9
	Basisvoorziening				6,7	98,9	2,0	28,9
	Infrastructuur				2,1	101,0	0,6	29,5
	Prestaties				94,6	195,6	27,7	57,2
Onderzoek			143,4					
	Strategie				15,5	211,1	4,5	61,7
	Basisvoorziening				14,6	225,8	4,3	66,0
	BaMa-koppeling				18,1	243,9	5,3	71,3
	infrastructuur				30,6	274,5	8,9	80,3
	Prestaties; landelijke par.				16,7	291,1	4,9	85,1
	Prestaties; Delftse par.				50,8	342,0	14,9	100,0
		Blauw		22,8				
		Rood		15,6				
		Groen		12,4				
Totaal			342,0			342,0		100,0

Figure 4.3: Budget proposal for 2005 for TU Delft. (Source: Financiele Kaderstelling 2005-2008: de Boer, 2004) Instellingscomponent: Institution component Onderwijscomponent: Education component Onderzoek: Research Bedrag: amount Totaal: Total

Finally the output of the university according to 'TU Delft in Beeld 2003-2004' (P37) was examined. In 2000, there were 172 dissertations completed, but in 2003 the number was 185. The number of scientific publications in 1999 was 4407, but in 2003 it was 5751. All these facts show that the output of research in TU Delft has been increasing over the years.

Therefore, from the viewpoints of both the number of staff who are involved in research, and the input and output of the university in research domains, concrete facts have established that **TU Delft is increasingly a research institution**.

2. Is there any proof to show that multiple-disciplinary efforts improve research productivity?

The efforts to develop multiple-disciplinary research in TU Delft started in 1997, when the DIOC (Department of Inter-Faculty Research) was founded. The initiative achieved its peak when in 2003, thirteen Delft Research Centers were across different disciplines. The aim of the establishment of these multiple-disciplines researchers was to meet rising demands for solutions to more complex issues in a society with diversified needs. These complex problems need to be studied from a multidisciplinary perspective to find *robust* and *sustainable* solutions. The thirteen

Delft Research Centers are thus supposed to provide integrated solutions to these multidisciplinary problems by drawing together high quality research. In this way, the knowledge and expertise built up over the years (in other words *long term*) on thirteen important research themes is made available to society, industry and policy-makers. Therefore the efforts aimed at multidisciplinary developments at TU Delft also aim at long term sustainable knowledge production.

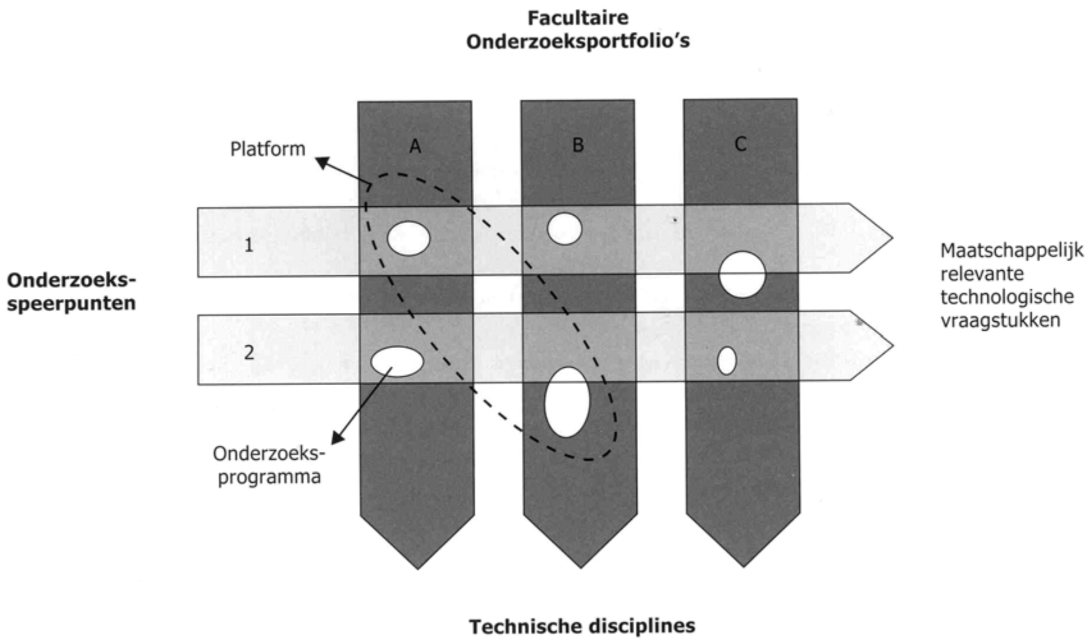


Figure 4.4: proposal for improving multidisciplinary research in TU Delft: source: Jaarverslag 2003 of TU Delft Facultaire Onderzoeksportfolio: Faculties' research files; Technische disciplines: Technical disciplines; Onderzoeksspeerpunten: Research spear point; Maatschappelijk relevante technologische vraagstukken: Social relevant technical pieces.

The question is: does multidisciplinary development improve knowledge productivity? The answer from the analysis seems to be 'Yes'. If we consider the publications of TU Delft within the ISI databases over ten years (from 1990 to 2001) as the main research product, we can identify four kinds of product based on different levels of cooperation: 1) Ps: products from a single group in faculty of TU Delft; 2) Pw: products resulting from inter-faculty cooperation within TU Delft; 3) Pn: products resulting from national cooperation; and 4) Pi: products resulting from international cooperation.

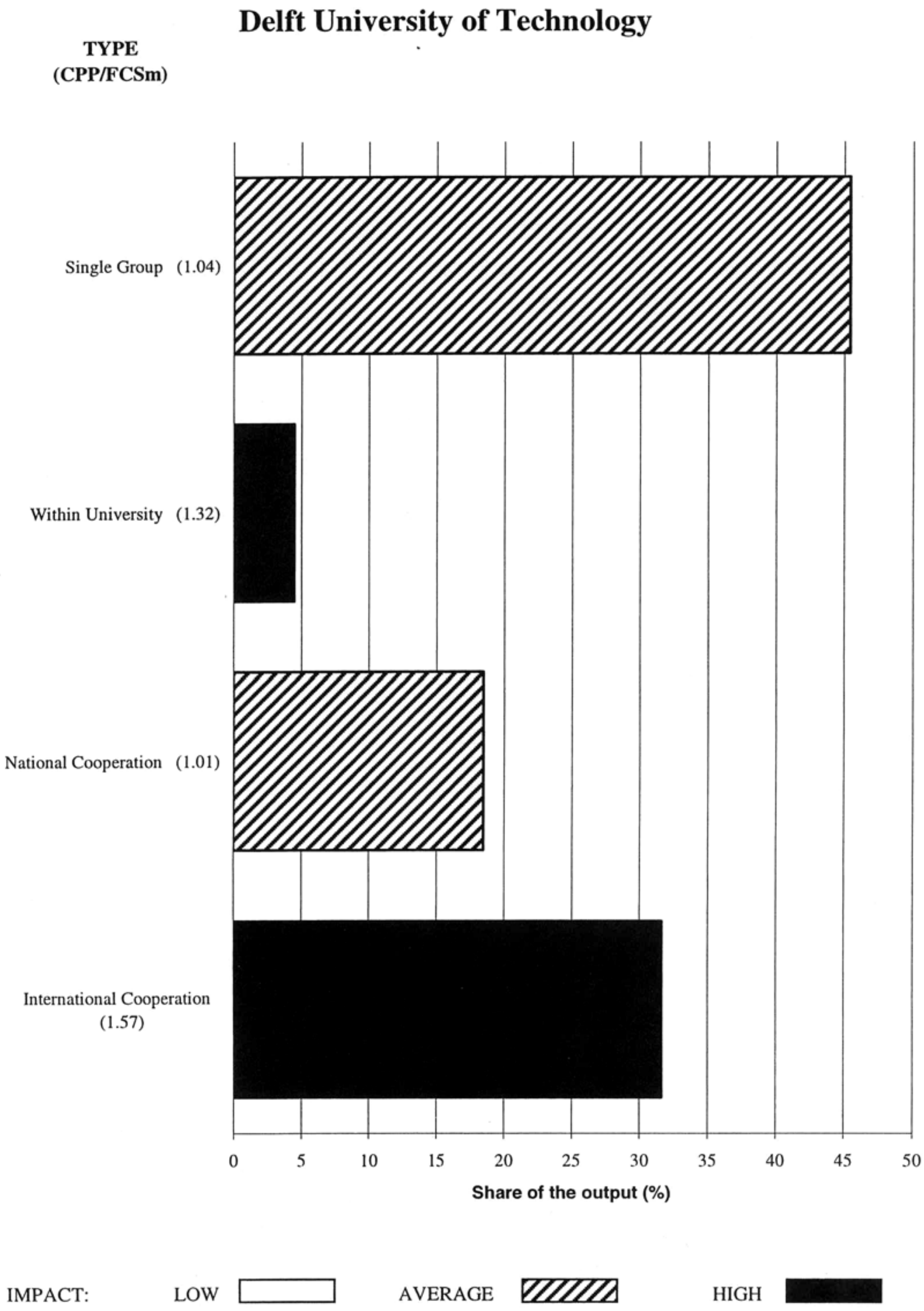


Figure 4.5: Scientific co-operation in TU Delft - output and impact per type, 1990 – 2001. Source: CWTS: van Leeuwen and van Raan, 2003) The darker the block the higher the quality

It was found that among the impacts of these 4 types of output, Ps represented the largest number of products, and Pi represented the best quality of products. We then further analyze the impact of these 4 types of product over 10 years.

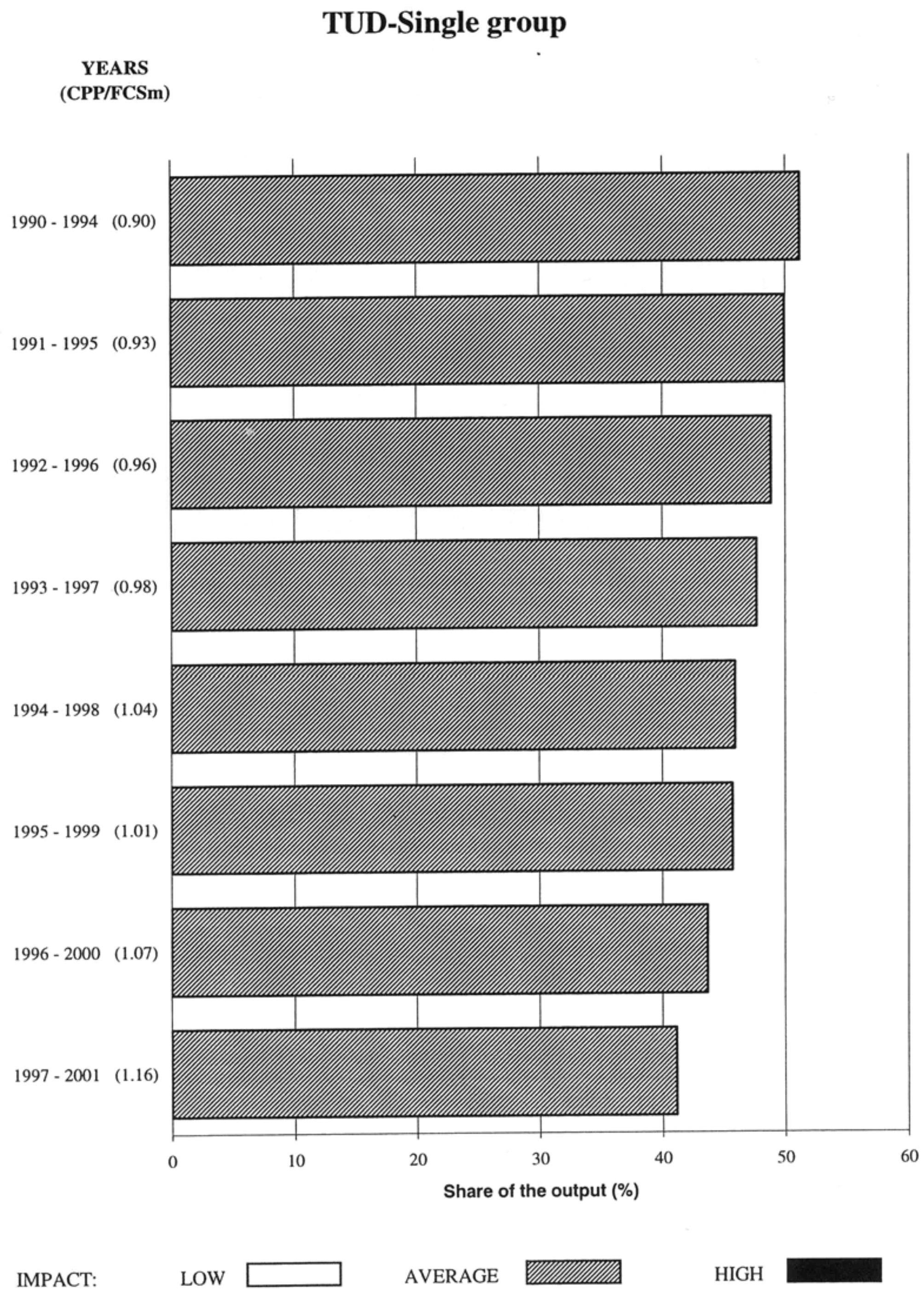


Figure 4.6a : Scientific co-operation in TU Delft - output and impact for different types of co-operation 1990 – 2001: single group (Source: CWTS: van Leeuwen and van Raan, 2003)

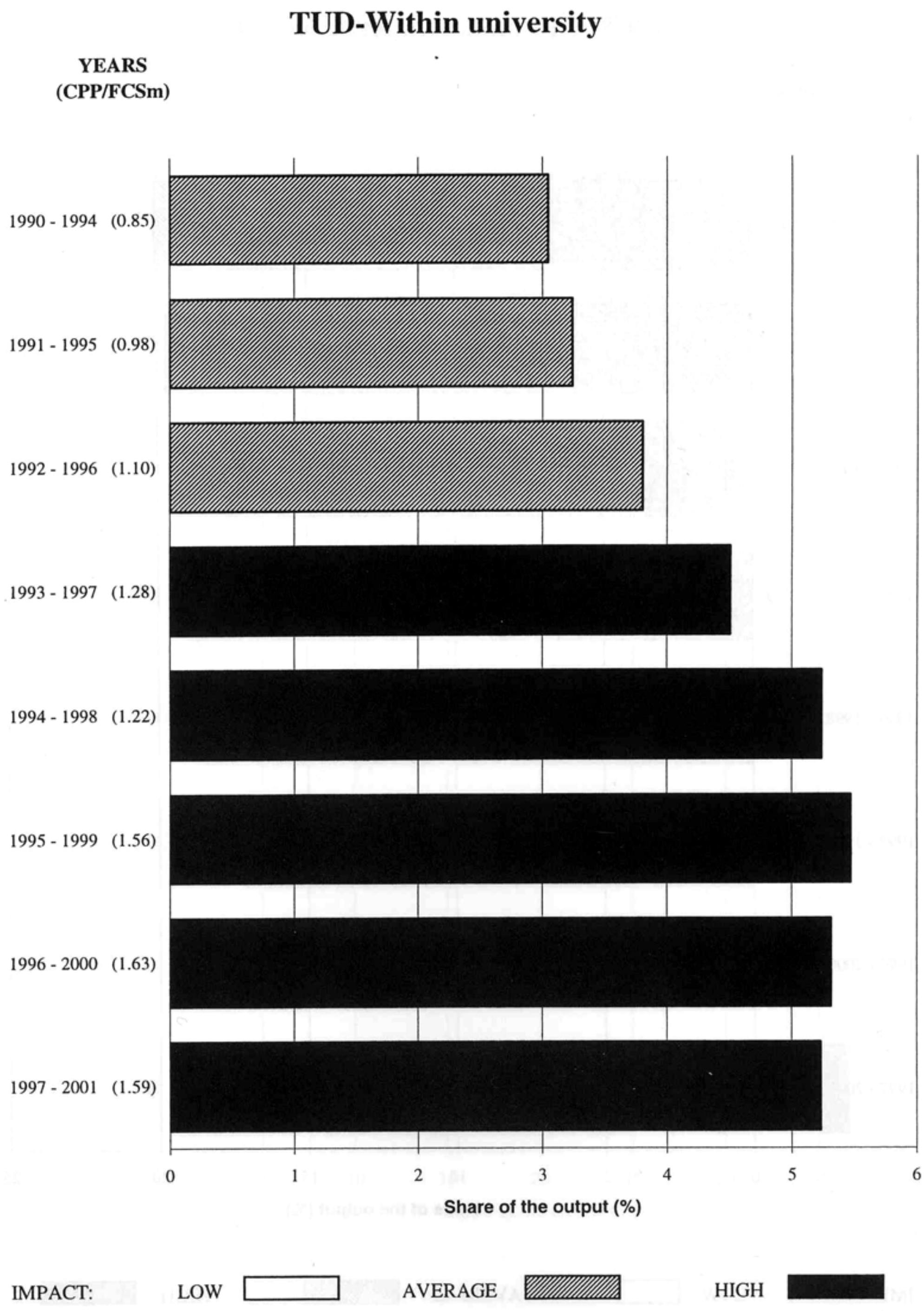


Figure 4.6 b: Scientific co-operation in TU Delft - output and impact for different types of co-operation 1990 – 2001: co-operation within university (Source: CWTS: van Leeuwen and van Raan, 2003)

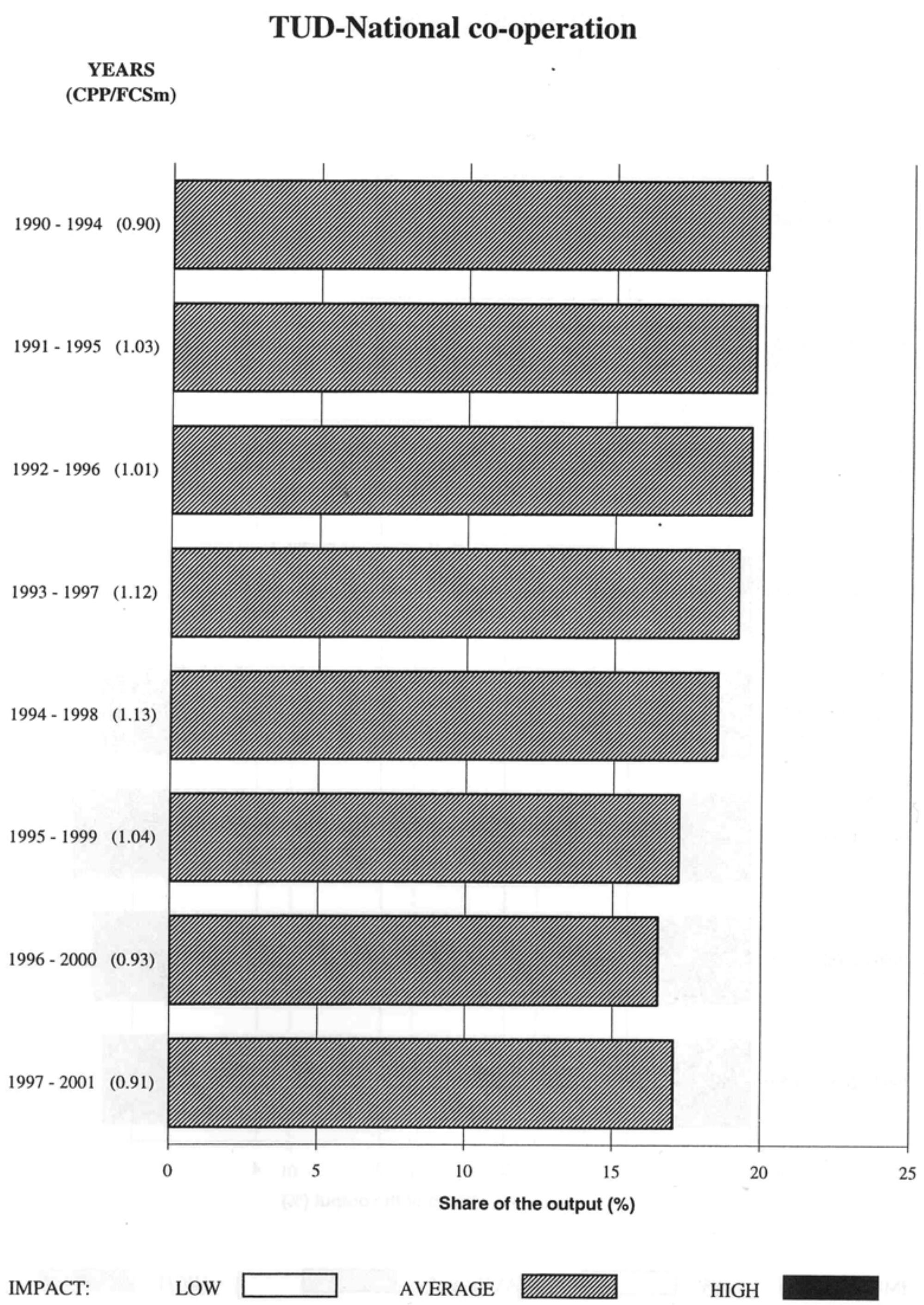


Figure 4.6 c: Scientific co-operation in TU Delft - output and impact for different types of co-operation 1990 – 2001: national co-operation. (Source: CWTS: van Leeuwen and van Raan, 2003)

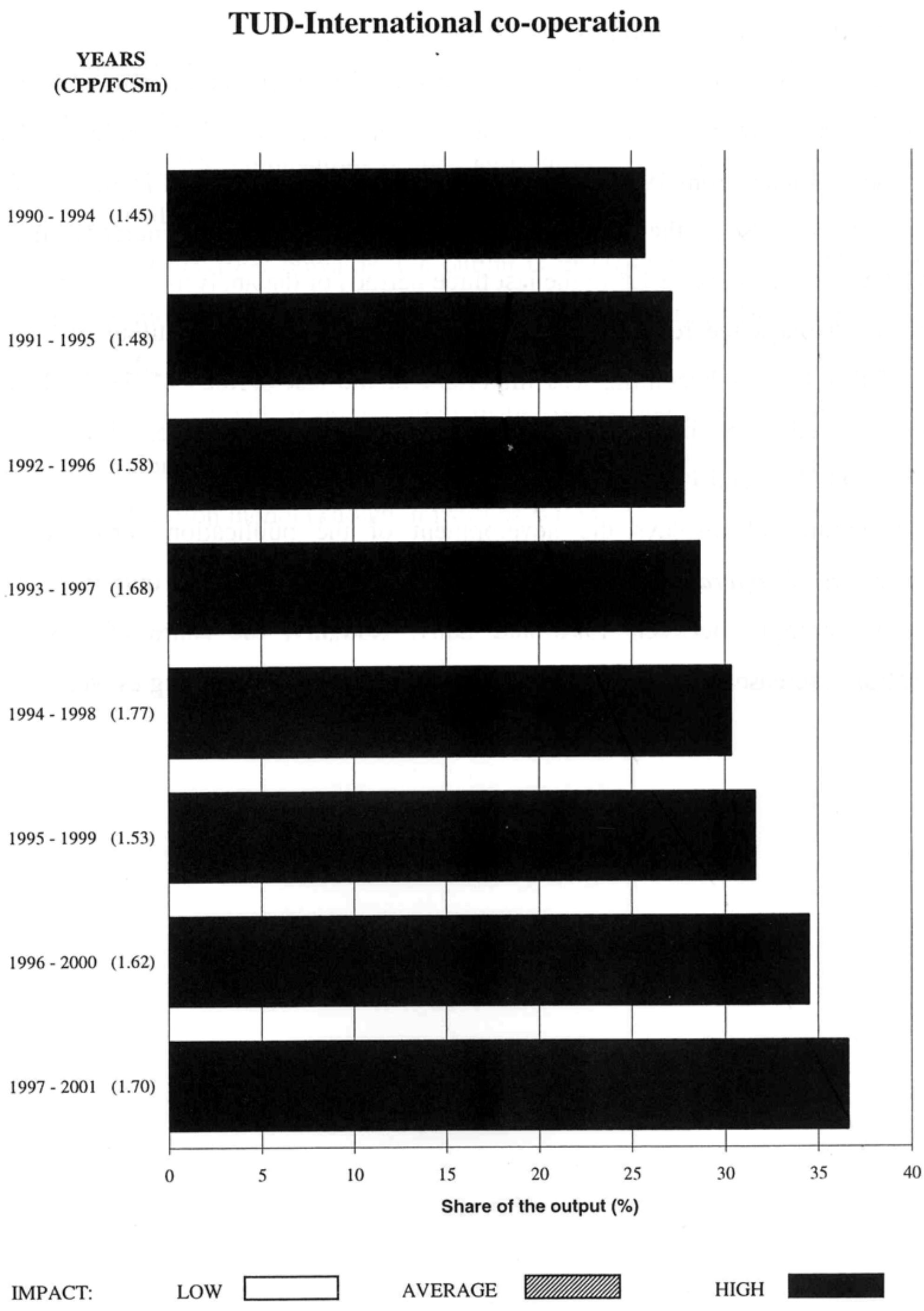


Figure 4.6 d: Scientific co-operation in TU Delft - output and impact for different types of co-operation 1990 – 2001: international co-operation. (Source: CWTS: van Leeuwen and van Raan, 2003)

From these figures it may be seen that when co-operation is made only in a mono-discipline single group, or only on a national level, the production of new knowledge declines over the long term (see Figure top left, and bottom left). When co-operation is made on an international level, the production rises (see Figure bottom right). However, the cost of production is very high. When co-operation is made on across disciplines within the university, both the quality and amount of new knowledge production increase dramatically!

The conclusion which can be drawn from the above is that: **when new knowledge production is organized across disciplines, both the amount and the quality of the production increase over the long term.**

From the documents collected and results of the interview with the administrative staff of the university, it can be concluded that TU Delft is increasingly a research institution, and when new knowledge production is organized across disciplines, both the amount and quality of the production increases over the long term. This is consistent with our conclusions from previous chapters, namely that diversity and clusters play important roles in maintaining sustainable knowledge producing over the long term.

The next question for consideration is: does the existing spatial structure provide the potential to bring people from different disciplines together in routine campus life. This will be investigated in the next section of the chapter.

4.3.2 Design of the Case Study

The case study method applied to TU Delft followed the six steps described earlier to study the key issues in Innovation Facilities. The case study method is applicable to this set of users because it can be used to heuristically examine the issue of to what extent the campus' topological network is compatible with encouraging the interaction of diverse researchers from different disciplines.

Step 1. Define the Research Questions

The primary purpose of this case study is to investigate to what extent the current campus provides potential opportunities for users from diverse disciplines in cluster to meet each other. In later chapters it will be explained why meeting face-to-face is so important in today's Innovation Facilities in the New Environment. In short, the questions to be investigated are:

1. **Are** students from different faculties able to meet each other easily in current campus layout, **or not**?

2. When using current campus layout, **when, where, and how** do students meet each other?

3. **What circumstances** allow students to meet and what circumstances prevent them from meeting?

4. Generally, **How much time** do students spend on e-communication, and what is its effect

Step 2. Select the Cases to be Studied and Determine the Data Gathering and Analysis Techniques

The reason why TU Delft was chosen as the subject of a case study has been explained. The collection of data covered multiple sources and types of data, including maps, historical surveys, data on the current situation, and other documents. Interviews were undertaken with the administrative staff and representative students in close social connection from 6 typical faculties, from which the distance to the center of the campus varies. The questions in the interview with the students included: when, where, and how they meet each other in a typical day on the campus? Using these data, it seemed that both a preliminary analysis and a more in-depth study were necessary.

Step 3. Prepare to Collect the Data

Preparation included: contacting each faculty to be studied to gain their cooperation, explaining the purpose of the study, and assembling key contact information.

Step 4. Collect Data in the Field

A representative student from each faculty was first identified. The students were then interviewed in their faculties to carry out the survey, and relevant documents and information were collected. Notes were taken during the interviews and field notes recorded after the interviews were completed.

Step 5. Evaluate and Analyze the Data

A preliminary analysis was the first technique used on the data from each student under study. This made use of the documents and results from the interviews to determine the potential for meeting, and to prepare the data further for the subsequent in-depth analysis. Problems and the causes behind them were examined. The unit for people is the number of students. The unit for space is the number of places. The unit for time is seconds. The unit for activity is time phase. The key unit is the number of times the students meet each other.

Step 6 Prepare the Report

The research report for the case study will cover the collection of data, analysis from the data, and conclusions from the data, which will help in developing the criteria for constructing the design tool.

4.3.3 Profiles used in the case study

Spaces Profile: 8 locations were investigated: Faculty of Aerospace Engineering (hereafter referred to as L1); Faculty of Architecture (L2); Faculty of Civil Engineering (L3); Faculty of Electrical Engineering (L4); Faculty of Industrial Design (L5); Faculty of Technology and Management (L6); Central library (L7); Aula (L8); and places outside the campus (L9).

People Profile: Representative students from the six faculties considered were selected as mentioned above. They are referred to as S1, S2, S3, S4, S5, and S6 from L1, L2, L3, L4, L5, and L6, respectively. We choose students as our objects to be observed. The issues identified in students can still be representative of researchers for three main reasons. First, the purpose of the preliminary case study is heuristic. It is to help in the search for the identification of the main issues in the campus and of the criteria for the adequacy of the design tool. It helps us to understand the role of the topological network in the organization of a campus, an issue which affects both students and teachers alike. Second, we have mentioned in Chapter 1 that in the New Environment, the boundary between teaching and researching is dissolving. Students are increasingly playing a more important role in research. In particular some of these six students are PhD candidatse and student assistants who are heavily involved in innovative research activities. Thirdly, students are typical agents in the campus, who can, at least in part, reflect the activities of those pure researchers who focus only on pure innovation. If the meeting potential between students is low, then we can conclude that the meeting potential between pure researchers is even lower, since they never attend courses and seldom step out of their offices.

Activities Profile: Mainly activities inside the campus were considered. These activities are identified as follows: participating in a lecture or seminar, A1; study or reading, A2, eating or drinking, A3; moving between rooms or buildings, A4; and other activities off campus, A5.

Time Profile: Time was measured in the unit of seconds (Time spent travelling was split into two types depending on the mode of transport: by bicycle and on foot).

Discipline distance: The key differences between the six different disciplines were considered by measuring distance between disciplines. The longest distance between disciplines seems to be distance between discipline S1and S6. Therefore S1 and S6 have the biggest differences of disciplines between each other. The disciplines can be roughly categorized into 3 groups, namely the arts group (S2, S5), the pure science group (S6), and the technology group (S1, S3, S4).

Questionnaires were completed by these representative students. These data were collated into tables which clearly illustrate which student was doing what, when and where on a typical day.

4.4 Preliminary Analysis of the Case Study Results

We then will carry out the preliminary analysis relating to those questions posed at the beginning of 4.3.2.

4.4.1 Analysis 1 - Do meetings take place?

Questions 4.1: Whether or not the diverse students in a social cluster have the potential opportunity to physically meet each other on basis of current campus layout?

Table 4.1 and 4.2 were analyzed to see whether or not these students had the opportunity to meet each other, and how many times this occurred during the day. The results are summarized in table 4.3, which shows when each combination of students had opportunities to meet.. All possible pairs of students in all possible time phases were considered, giving a total of 15*15=225 possible meetings. Of all these possibilities, surprisingly only 9 potential meetings occurred during the whole campus day. The rate of potentiality of students' meeting is thus 9/225 = 0.04 (4%) which is very low! This indicates that students from different disciplines only rarely meet each other as a normal course of events in a routine campus day. The profound consequence of this situation will be analyzed further in later sections relating to changes resulting from the New Environment.

Conclusion 4.1: In a routine campus day, the potential for meeting between students from different faculties is very low. In other words, the diversity in interacting clusters is very low. Although in this case we only studied the issue of potential encounters between students, a similar situation exists widely among researchers. In fact the potential of encounters between researchers is even lower, since most researchers have no courses to attend on the campus and seldom step out of their offices.

4.4.2 Analysis 2 - Circumstances of meeting

Question 4-2: In a routine campus day, **who meets whom, when and where**?

To answer these questions, the relevant data was extracted from table 4.3 to form table 4.4 in which the detailed circumstances of potential meetings are summarized, while situations that could not lead to a meeting have been eliminated. It can be seen that most potential meetings occurred during break time (6 occurrences) or lunch time (2 occurrences); only one occurred during a formal course session. Most of these meeting opportunities occurred on roads on the campus (4) or in the public spaces of the faculties (4); only one was in the public space of the library. Most of these potential meeting situations may be classified as "short & informal" (7 occurrences); there was also one each of "short & formal" and "short and formal".

Conclusion 4.2: In a typical campus day, potential opportunities for meeting occur mainly during periods of informal time; they occur on formal or informal spaces; and they occur mostly as short and informal meeting.

4.4.3 Analysis 3 - Factors influencing the likelihood of meeting

Question 4.3: 3. What circumstances allow students to meet and what circumstances prevent them from meeting? **Why** they can or cannot meet each other under current circumstance? Generally, **what** are the basic constraints which determine whether students can or cannot meet on campus?

The collected data were analyzed carefully. The aim was to answer the question: if two students were able to meet each other, what made this possible? Similarly, if not, why not? What were the reasons and conditions giving rise to those meeting opportunities? All the possible meetings occurred in 9 different time-phases. These time phases were analyzed to see how those meetings were able to occur. It was found that, the meeting times lasted from 0 minutes to a maximum of 30 minutes, which occurred in the lunch canteen. The most frequent type of meeting was a D+D (Dynamic + Dynamic) meeting which occurs between persons who are moving, and the least common was S+D (Static + Dynamic) meeting which occurs between a person who does not move and a person who moves. The most common place of meeting was near L8, which is actually near the center of the campus. The meetings usually happened during lunch time, break-times or when students were leaving for home. The highest quality meeting took place in the lunch canteen. The lowest quality meetings where usually type D+D meetings.

First of all, distance from the current location to a potential meeting place was an important factor; if the distance is too great, then meetings will not occur, since students will not wish to go there. As Student 2 commented: "*For coffee breaks (inside L2) I don't like the ground floor coffee area (cold) and actually I don't like any coffee areas in the Bouwkunde (the Faculty of Architecture). The Aula (L8) is better (better coffee + nice sitting area). Again just for coffee this is too far to visit, however*". Hence distance is a also key factor which determines whether or not a meeting can take place.

Secondly, the topological layout of the campus affects the meeting potentiality. Even the distances between a pair of locations in 2 different topological layouts are the same, the meeting potential in them can be different because of the topological constraints. . For example, if L1 were close to L6, then S1 wouldn't meet S4 during the time phase 10:30 to 10:45.The reason is clear: the topography decides the routes that people have to follow, and so determines the probability of their meeting.

Thirdly, the teaching activity locations seem to be another factor which determines whether or not students can meet. When Student 1 was asked why he had come from his distant faculty (L1) to L6, he said that he had a course session in L6, and so he had to be there. This fact reveals that if students' course sessions were sometimes arranged outside their own faculty, then they would have a greater chance to meet students from different backgrounds or disciplines.

Fourthly, the geographical relationship between the students' houses and their campus also plays some part in determining the potential of meeting. For instance, considering time phase 12:30 to 13:30, if Student 6 's home were in the opposite direction to where it actually is, he would not meet Student 1 on his way home.

Fifthly, social relationship also plays a role in determining meet or not a meeting takes place. When Student 6 was asked why during time phase 15:45 to 16:30 he went to L4 to study, he said that Student 4 was a close friend, so he tried to see Student 4, and hence went L4 to study. Therefore relationship (a kind of social relationship) plays a role in determining the flow of people on Campus.

Finally, means of transport also influences the meeting potentiality. For instance, during the time phase 12:30 to 13:30, if S6 had gone to L9 on foot instead of by bicycle, he would not have met S1 who was traveling by bicycle in the same direction. Another example is that, if two students both take the bus to go home they might meet in the bus station or in the bus. If one of them went home by bicycle, then they would not meet. Therefore the means of transport is also a factor in influencing meeting potentiality.

Conclusion 4.3: Six basic constraints seem to determine the potential for meeting possibility on the campus:

1. **Distance between locations**
2. **Topology of locations**
3. **Scheduling and location of course sessions**
4. **Geographical location of students' houses relative to the campus**
5. **Social relationship (friendship causes meeting)**

6. **Means of transportation**

Looking at this list it is clear that only the first two directly relate to the architectural aspect of building complexes: 1) Distance and 2) Topology. The issue of scheduling and the location of course sessions relates to management. The location of student housing has to do with the urban design and the strategy planning.

4.4.4 Analysis 4 - The influence of E-communication

In Chapter 1, the possible influences of virtual means of knowledge production in the New Environment was analyzed according to existing theories. Here, in the case study, we can examine what the real situation is. **Question 4.4** asked: How much time do students spend on E-communication and what is its influence on potential physical meetings?

The questionnaire to students included three questions:

Question 1. “Is there somewhere that you would prefer to go during the breaks, but you cannot owing to the constraint of distance?”

Question 2. “How many hours do you spend on the Internet per day?”

Question 3. “If you do not spend your time on Internet where do you like to go?”

The answers to these questions can be found in table 4.9 in the appendix.

The first issue is how much time these students spend in which activity during the day. In table 4.10, the numbers of minutes students spend on different activities are further analyzed. These data were transformed to a figure (figure 4.7) to illustrate the amount of time spent by the students from the different faculties on different activities.

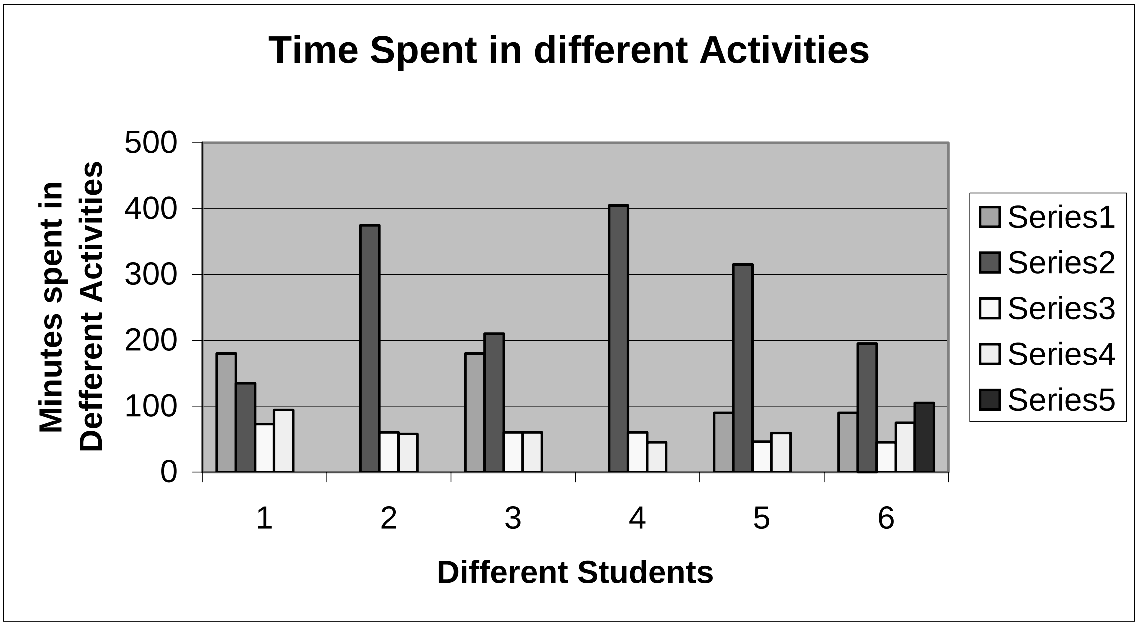


Figure 4.7: Time spent by different students on different activities

Series 1 - attending course sessions; Series 2 - studying or reading; Series 3 - eating or drinking; Series 4 - moving about; Series 5 - other activities outside Campus.

It may be seen that the students spent the greatest amount of time on self-study or reading. Only Student 6 undertook activity outside the campus during daytime. The average time they spent on moving about (including moving both within their faculty and between faculties) was about 10%. It was found that time spent traveling can provide high potential for possible interaction across different faculties.

Secondly, we can consider how much time the students spent in which place during the day. These are shown in table 4.11, and this data was used to construct Figure 4..8 which shows how much time the different students spent in different locations. It may be seen that the 6 students spent time in very different places on the campus and outside the campus. Surprisingly, some students (e.g. S3 and S5) spent almost the whole day only in their own faculties; they had no chance to meet students from other faculties! This reduced their meeting potentiality to a minimal level, which is not good for cross- discipline interaction. The average percentage of time they spent on moving about inside their faculties or between different faculties is about 8.6%. This time phase offers a high potential for possible interaction, as mentioned above. However, the table below demonstrates that during this time of high potential for interacting, most students spent time on the Internet instead of going out for a break.

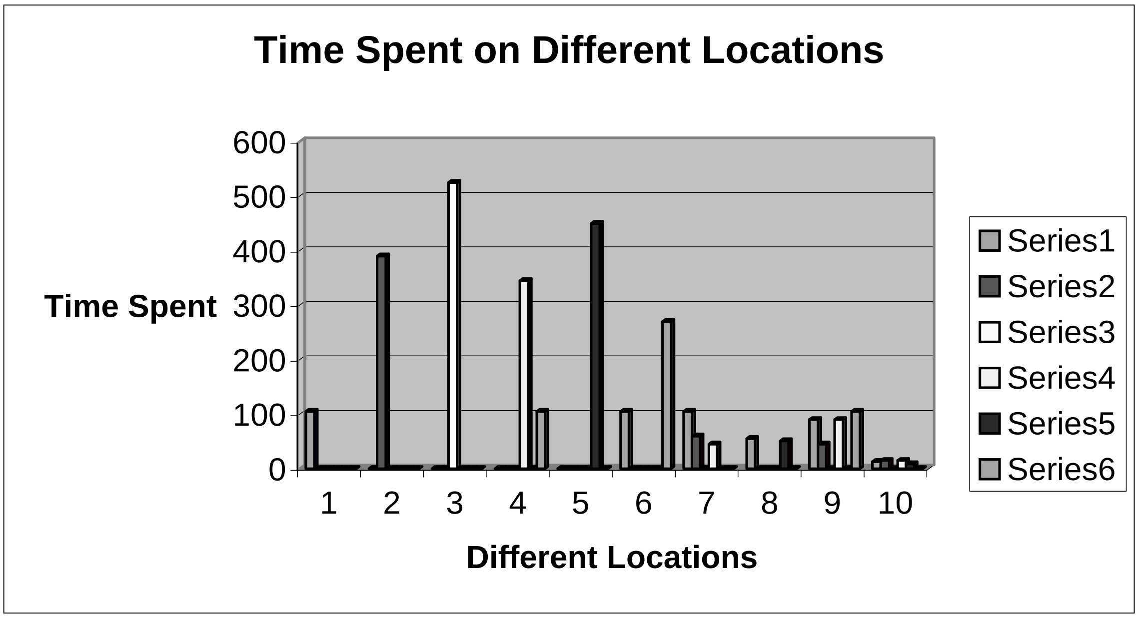


Figure 4.8: Time students spent in different locations.

Conclusion 4.4: Students spend so much time on E-activities that they have less to spend on face-to-face meetings, although the time phases spent on E-activities are actually times offering high potential for possible multiple-discipline interaction[7].

7 A similar conclusion was drawn in research in MIT by a team from Aero & Astro Faculty (Corry R. A. Hallam, 2000). The research is a response to change in learning environments. In an article entitled 'From Teaching to Learning – A new Paradigm for Undergraduate Education', Robert Barr and John Tagg (1995) argued that: "a shift from Instruction paradigm to Learning Paradigm is taking hold in American higher education." In brief, the shift may be thought of as a transformation from a faculty and teaching centered model to a student and learning centered model. This shift reshapes many things, including the learning environments in which the education activities take place, and the manner in which the learning environments are developed and managed. In their research, they observed the time students spent on various activities. They found that nowadays most time is spent by students spent on PCs instead of in classroom, as it was 20 years ago.

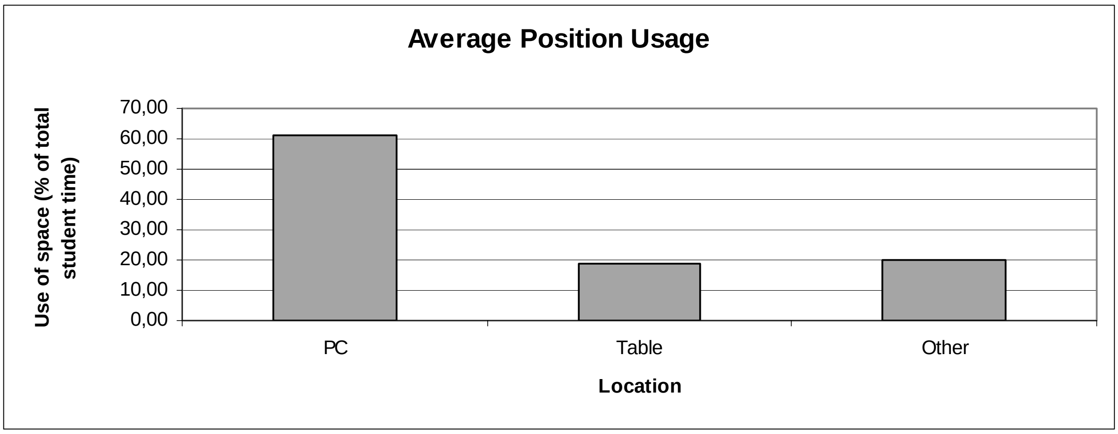


Figure 4.9: Average usages of position of MIT students (Source: Internal report of MIT Aero & Astro, 2000, provided by Prof. W. Porter)

4.5 In-depth Analysis and simulation of the implications for an Innovation Facility

Basic findings have been drawn from the previous preliminary analysis. The main problem in current Innovation Facilities can be identified as too low a possibility of meeting between agents from different faculties (or too low a potential diversity in interacting clusters). Six factors have been identified as necessary conditions for determining the meeting potential in Innovation Facilities. The next question is: What will be the consequence of these findings for the New Environment? This requires an in-depth analysis relating to changes in the New Environment, which were introduced at the beginning of the dissertation in the context of existing literature. The next question to be investigated is Question 4.5: What will happen if there is only a low meeting potential across disciplines over the long term, taking account of the E-media used in the New Environment? It is difficult to extract the long-term impact either from existing theories or from long-term observation. However it is possible to be analyzed by scientific reasoning and simulations, even some literatures (Van Alstyne and Brynjolfsson, 1996) have similar conclusion.

To investigate the possible consequences, agents may be represented as nodes; the connections between them are represented as linkages. In this way it is easier to see the changing interconnections between nodes in a system which changes over the long term. The assumed situation is that from time phase 1 to time phase 5, there are different agents acting in the system, which result in different consequences. Some interesting rules regarding the network can be identified through this simulation.

Phase 1: In an Innovation Facility, suppose there are 3 faculties, and each faculty has 4 professors. The central node in each faculty is the Dean. These 3 faculties are connected with each other by Deans’ connections.

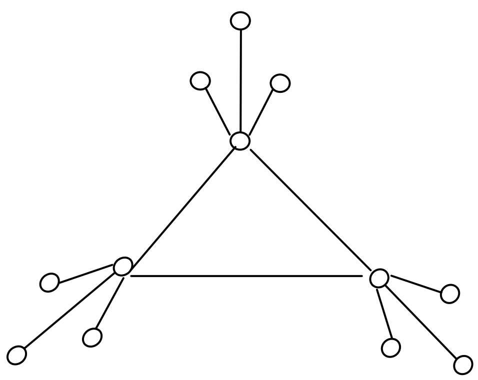


Figure 4.10: Phase 1 of the simulation

Phase 2: As time elapses, more connections are built inside each faculty by physical interaction. The diagram uses double-lines to indicate the connections built in this phase.

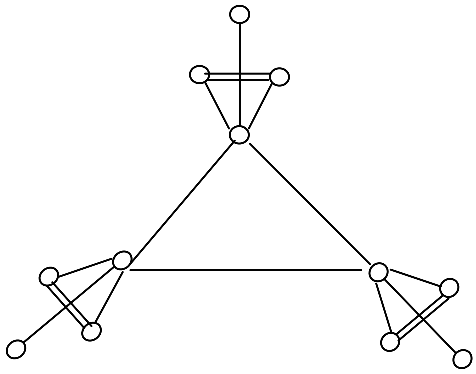


Figure 4.11: Phase 2 of the simulation

Phase 3: As time elapses, more connections are set up inside each faculty. The diagram uses the triple-lines to indicate the connections built in this phase.

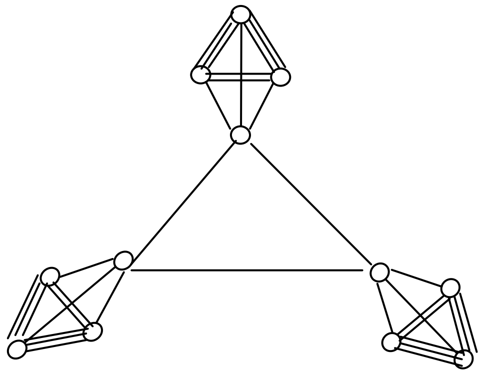


Figure 4.12: Phase 3 of the simulation

Phase 4: At this point a powerful new media (the Internet) suddenly intervenes in the this network. The Internet can be connected very easily to any nodes in the system, instead of relying on the connection through their dean in a traditional hierarchical structure. This change shakes the above traditional connections. Anyone who is part of the network can connect to any other person via this new media. This time a bold line is sued to mark the new connections inside the system.

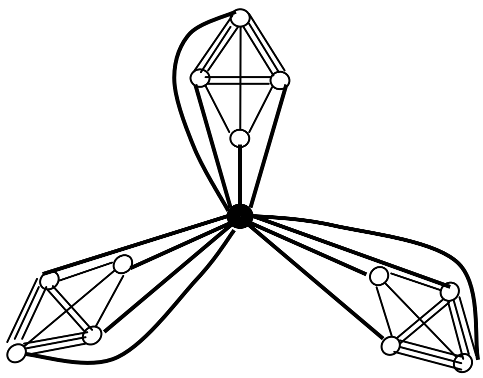


Figure 4.13: Phase 4 of the simulation

Phase 5: As use of the new media grows, crucial change occurs. It is so convenient for every one to connect with each other through this new media that everyone's direct connection with each other fades gradually. Finally, the whole network relies only on the new media. At the same time the internal physical interactions disappear.

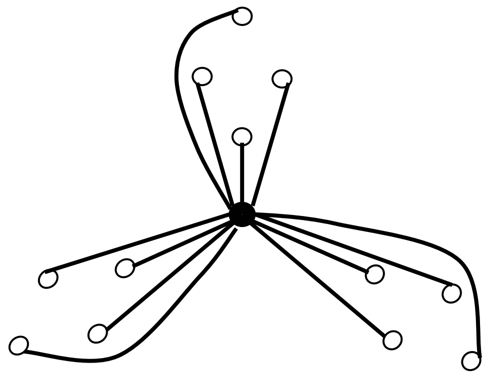


Figure 4.14: Phase 5 of the simulation

Now let us list the changes of the interconnections resulting from this process.

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Interconnected linkages	12	15	21	30	12

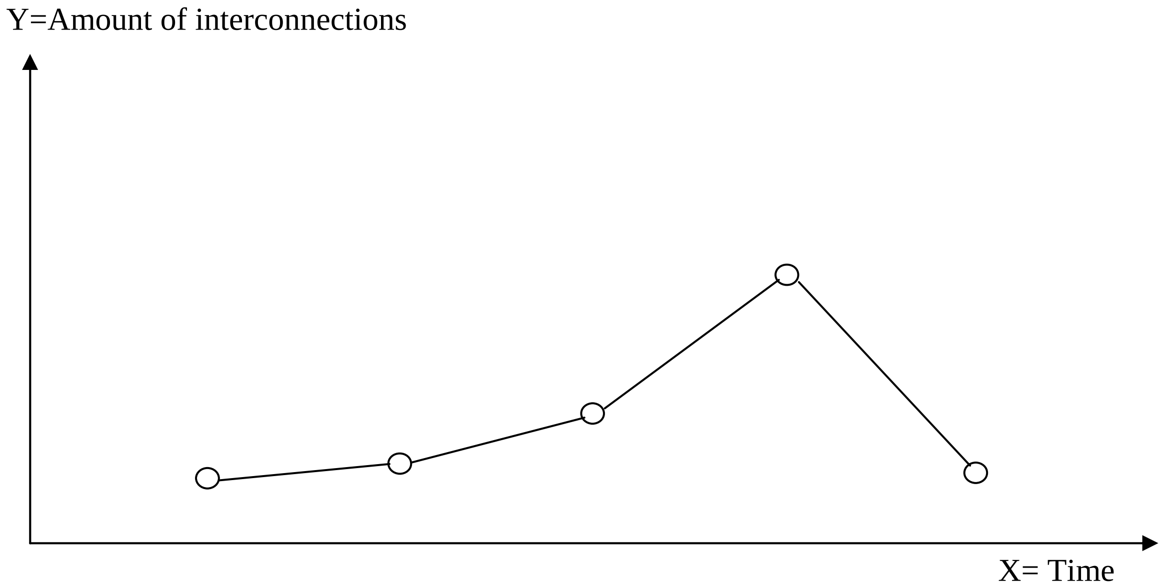


Figure 4.15: Interaction of diverse researchers over long-term in the simulation

The conclusion from the simulation is that: in the New Environment, while the use of E-means is increasing, the diversity in physical interaction has to be enhanced to keep a fine balance combining the advantages of both approaches, so that sustainable innovation can be possible.

4.6 General Concluding Remarks from the case study

Conclusions from the preliminary analysis of the case study show that: the potential interaction between diverse knowledge agents in cluster is very low. The conclusions from the in-depth analysis of the case study are that the potential diversity in physical interaction has to be enhanced.

In chapter 2 it was concluded that maintenance of the long-term sustainable production of new knowledge requires the interaction of diverse researchers from different disciplines and that these interactions occur and evolve in clusters in Innovation Facilities. However, the results of the study described in this chapter show that such types of diversified interaction in clusters seldom occur in current Innovation Facilities.

As a result, the way to design Innovation Facilities with a high potential for physical interaction across diversified disciplines is needed very urgently for maintaining sustainable innovation in the New Environment. The most important lesson to be drawn from the case study is that the physical organization of the facility is one of the necessary conditions that have a potential impact on the diversity of people interacting and forming a cluster. Thus the challenge posed now is to find out how precisely this physical organization can be controlled, so as to offer conditions that permit the formation of high diversity clusters of interaction.

The next question may be posed thus: are there existing theories relevant to the design of Innovation Facilities with a high potential for interactions across diversified disciplines, or do existing theories only offer a minimal contribution to the development of a new design tool that will help with this. This will be discussed in the next chapter.

CHAPTER 5

EXISTING THEORIES RELATING TO INNOVATION FACILITIES

Understanding the limitations and applications of existing theories relating to Innovation Facilities

This chapter reviews existing theories which have been applied and are related to the structure of locations in space and the generation of new knowledge. In particular, the focus is on work related to facilities producing new knowledge. The advantages and disadvantages of these theories are analyzed, along with their relevance to the design of such facilities. Possible aspects of these theories for use in constructing a new design tool targeted at facilities for sustainably generating new knowledge are identified.

In our presentation we do not include theories that relate space-time constraints to the accessibility of places from other locations, or of groups from groups, as the Hägerstrand model (and the models of his followers), of innovation diffusion in space does. Our model focuses on topological constraints which ignore Euclidean metrics and time distance. And therefore we mainly concentrate on the consequences of the topological network structure of locations in which researchers are interacting to product new knowledge.

5.1 Bullock, Dickens and Steadman' s theory of campus design

5.1.1 Summary of the theory

During the 1960s 'Cambridge Urban and Architectural Studies' led by Martin were carried out to investigate the ***potentialities*** of the geometries in university campus as diverse types of spreading forms within which individual faculties could more easily ***intercommunicate*** and changes of size could be more readily accommodated (Martin and March 1964). Among these observations, 'A theoretical model for university planning' by Bullock, Dickens and Steadman introduced a theoretical model focusing on: *standards*, *conditions* and *organization* as they existed in universities in those years. The construction of their model started from two bases: first, the relating of population---staff and student numbers---to the total space (measured in terms of floor area) required for their accommodation, and second, relating of these floor areas to the consequential volume of buildings and thus the area of land used. Bullock, Dickens and Steadman believed the core solution for efficiently using classrooms was determined by the goodness (or efficiency) of fit between group size and room size. They drew a 'network' with the following indexes: context; population; activities; building form; and evaluation. According to their model, for a given set of population figures, it would be possible to calculate the total space (in terms of floor area) requirements in teaching and research buildings by classifying a number of '*room types*' identified by use rather than by architectural characteristics. This model[1] revealed how widely building costs and pedestrian movement vary with different layouts. The final stage of the model comprised a rudimentary representation of the urban context of the university, which showed the distribution of student residences throughout the town in relation to teaching and research sites, identified by varied land values and rent levels, as well as the overall traffic network[2]. The next step was to reveal the factors that affect these activities. They admitted that the method they proposed might raise some technical difficulties; therefore they strongly suggested taking advantage of simulations in the research. The possible difficulties could be avoided through the use of an entropy maximizing method of the type proposed by Wilson (1971).

5.1.2 Relevance and application to Innovation Facilities

There are five important achievements in Bullock, Dickens and Steadman's research, which can be accordingly used in our research for today's Innovation Facilities.

1. Blurring between teaching and research

Firstly, Bullock, Dickens and Steadman claim that the main difference between old universities and the new universities of their time was the breadth of the courses they offer. The greater the choice of the students' courses, the more complex the interlocking of different courses becomes. This is the similar to what we have

[1] The application of the model can be extended to the sociology of student housing and the comparative educational advantages of different types of accommodation and of different social groupings (Robbins 1963, Allen and Miller 1966).

[2] To verify their assumptions and conclusions, they processed some simulations. They firstly classified the original 330 diary activities into 48 categories. The next step was to examine the composition of time-budgets to find different groups of students who vary in the total times they spent on each of these 48 activities.

concluded in the case study of TU Delft that 'course scheduling in the campus can potentially determine the profile of meetings between students'. In the New Environment we identified that a blurring occurs not only between courses but also between teaching and research. The spatial layouts of today's university should respond to this new requirement.

2. Layout of space

Secondly, by representing certain characteristics of the university, the *layout of space* (in terms of the number and size of teaching rooms) and the *distances* separating these spaces provided the possibility to explore the consequences of particular plan forms for patterns of teaching and their relative levels of spatial operation. In today's universities, whose main function is increasingly research, we will consequently develop our own model to study the *layout of space* and the *topology* separating these spaces in order to explore the consequences of particular plan forms on patterns of research and their relative levels of spatial operation.

3. Topological constraints

Bullock, Dickens and Steadman's third salient conclusion was that the layouts of different universities could be characterized by a general system in which three features were the most important: 1) *Density*; 2) *Zoning*; 3) *Route structure*. Density includes both an overall density and the variations in local density from one part of a site to another. Consequently, this variation turns out to be related to the uses of different spaces and the types of activity in different parts of a site (or between these sites). Furthermore, a structural route would include paths and roads crossing those sites, which could be categorized as horizontal routes (for example, corridors inside buildings) and vertical routes (for instance, lifts and staircases inside buildings). In our research, the high-density zoning of locations and their users will be classified into 'clusters'; the route structure (mainly the horizontal routes) will be studied in terms of 'networks'.

4. Typological constraints

Finally, the most significant contributions of Bullock, Dickens and Steadman's research are that they realized the typological characteristics of these spatial layouts in university planning. They firstly pointed out two extremes in university planning: the dispersed, or American, style, and the centralized, or English, style. They went on to cite 3 types of university spatial layouts, namely: 1) the 'linear' type system (for instance, the University of Bath); 2) the 'nuclear' system (for instance, the University of York); and 3) the rectilinear gridiron plan (Berlin Free University). In our research, the typological constraints will be studied on the basis of '**prototypes**' which are believed to play an important role in generating design solution.

5. Input-output matrix and Simulation

They also suggested that another type of model might provide the opportunity to reproduce the movements of students, not in their day-to-day activities, but over the longer period from one academic year to the next. For this purpose, a so-called 'input-output matrix' model was proposed. This model described flows of students from courses to courses and from year to year at the level of the individual institution. The proposed 'input-output matrix' effectively represents students' flows both in space and time. In our research there will be another system of representation to identify the flow of input and output. To identify and understand problems, **simulation** is an effective means. In a later chapter we will also employ simulation as an important means of explaining the application of the design tool.

In short, from Bullock, Dickens and Steadman's theory, we can summarize the following main possible applications: 1) Innovation Facilities can be studied by observing **space-time-activity constraints**; 2) An effective model of observing these space-time-activity constraints is by use of a **suitable model**. (Both applications 1) and 2) which involve Space-time aspects, however, will not be addressed in this research. On the other hand they should be considered as part of a future extension of this tool, as we indicate in our conclusions.); 3) **Density, Zoning, and Route structure** are possible channels to observe space-time-activity constraints, and high density zoning can be identified as '*clusters*'; the route structure can be represented in a '*network*'; 4) Identifying **basic types of spatial layout** is a simple way to realize a complex design solution, which can be developed into 'prototypes' in design; 5) To identify and understand problems, **simulation** is an effective means.

5.2 Dober's theory of Campus Design

5.2.1 Summary of the theory

Dober believes that campus design is the art of campus planning, the culminating act of those processes and procedures that give form, content, meaning, and delight to the physical environment serving higher education, in which the sense of place, the sense of history, the communication of an institution's purpose, presence, and domain, and the generation of symbolism should be highly stressed. Therefore, the campus planner's challenge is: "*to determine a physical concept in which image and reality are not far apart*" (Dober, 1992). Considering complexity and changing of today's higher education, he tries to develop principles, methods, and procedures of campus design, which would have '*universal application'*. The approach he chooses combines aspects of traditional town planning and urban design techniques, contemporary participatory planning, and the ecological and visual heritage of landscape architecture. Dober investigates important concepts such as '*Landmarks*', '*Style*', and '*Materials*' in campus design with live examples based on American campuses. Dober stresses the importance of '*place-making* ' (PM) which was thought to be the key principle behind all campus planning. Dober points out that: "*At minimum, placemaking entails the positioning and arrangement of campus land use and pedestrian and vehicular routes, the location of buildings and functional open spaces, such as playfields and parking lots, the definition of edges, and the interface between campus and environs. A plan thus created serves as the framework for specific designers, enabling them to be integrated into a unified scheme to meet overall objectives, programmatic, functional, and visual*." Dober thinks that this kind of integration could ensure orderly and economic growth. For 'Placemaking', he proposes a nine-step process: 1) A plan for planning; 2) The campus plan agenda; site and environs analysis; progress report; alternatives; synthesis; reviews and revisions; documentation and dissemination; implementation[3].

Although Dober gave thoughtful ideas about campus planning, he didn't discuss diversity in detail. The interaction of diverse researchers has not been considered as one of the drivers in promoting economic growth in the knowledge industry. Dober points out that: "*At the important junctures in every campus history, one will find architecture and landscape embraced as an indicator of institutional change*". But there was no further analysis of the new changes resulting from the New Environment, or its impact on institutional change.

The Society for College and University Planning (SCUP) made a statement of principles for campus design. Among these principles, Statement 1 claims: "A Campus is a work of art, whose stewardship should command the attention and respect of **successive generations**". Successive generations in our research can be understood as 'Long-term generation of innovation' or 'Sustainable innovation'. Statement 3 claims: "Appropriate campus designs define and celebrate an **institution's purpose**, territory, accomplishments and aspirations". In the New

[3] In Dober's system, the image of the campus is the central target of research. Four key factors cause and control the image of the campus: Style (S); Materials (M); Landscapes (L); Landmarks (L). Dober listed 9 main reasons for preparing a campus planning. We here cite 3 important ones from them:

1. To help clarify, confirm or adjust institutional goals and objectives and priorities as they relate to the institution's physical resources, existing or desired;
2. To help define the physical resources required to sustain and/or advance the institution's missions, goals, objectives and priorities;
3. To describe and dimension physical improvements in general terms so as to have a reasonable sense of purpose, size, and probable cost.

Environment, we define an institution's purpose as 'to sustainably produce new knowledge'; one important means is to cultivate the interaction of diverse researchers in an institution.

5.2.2 Relevance and application to Innovation Facilities

What is important in Dober's system for the development of our tool is his stress of the 'long-term' function of the knowledge producing institution, which reinforces our starting point, and his insistence on the importance of routes, locations, positioning, and assessment, all of which point to the significance of the topological organization of the facility.

5.3 Horgen, Turid, Joroff, Porter and Schön's 'Process Architecture' theory

5.3.1 Summary of the theory

Horgen, Turid, Joroff, Porter and Schön suggest a new approach to creating workplaces, called 'Process Architecture' (PA) which can improve work practice and transform organizations. The 'Process Architecture' first urged us to rethink the dynamic relationship between work processes and the spatial, technological, financial, and organizational environments within which these processes occur. They claim that making an effective workplace requires collaboration between stakeholders with different interests, freedoms, and powers. Aspects of PA's practice are part of other approaches to workplace formation and many of its tools are in common use. The tools used in the PA are quite different from many current approaches which were crafted in a time of greater stability, when the future was assumed to be changing much less and more slowly. Conversely, PA is created for today's businesses which are in a more changeable world, where organizations and work processes are subject to continuous change, and where the technology of work changes rapidly and in frequent, unpredictable ways. Through a comprehensive explanation of the approach and framework, and with concrete case studies, the features, benefits, and challenges of PA are systematically presented.

First of all, PA describes an unstable environment in which most organizations are attempting to meet the new challenges of workplace formation. In this climate, it is necessary to rethink our New Environment and our new workplace. The new world is described as a world in which "*established values and assumptions are continually challenged; new competitors appear from unexpected locations; product life cycles* *grow shorter; deregulation undermines the old order; innovation sweeps established products and services aside; and customers demand greater speed, quality, and cost effectiveness*".

Responding to this changing new world, organizations are urged to rethink their business mission and strategy, reengineer work process, strive for higher quality and increased efficiency; and adjust to have less hierarchical form. "*Organizational change implies changes in work process, the organization itself, and business environment*". At this point of change, we have to rethink how work and the workplace should be accordingly defined, designed, and organized. Facing these new changes and challenges, PA proposes a theory structure based on four interdependent dimensions of the workplace: Space (S); Organization (O); Technology (T); Finance (F). The core of the research is 'Process Architecture' that can cope with change in the New Environment.

Considering the complexity and multiple-agents in the system, PA proposes 'Optimizing the workplace through collaborative engagement' between all 4 types of participant in the system, namely architects, economists, organizational analysts, and system and software designers. In such a chaotic situation, to avoid the risk that the workplace 'does not do what you want it do' Horgen, Turid, Joroff, Porter, and Schön propose a new theory framework for 'shaping and guiding workplace transformation'. The term process architecture thus implies that '*working toward workplace transformation is itself subject to careful design and craftmanlike execution*'. Its goal is hence a '*dynamical reinforcing relationship between work and workplace'*.

Another very important concept in PA is the concept of '*Clusters*'. In an example of hospital spatial reorganizing, PA clusters patients' rooms around a nursing station instead of in traditional parallel rows. The evolving cluster design represents an integrated set of spatial and organizational solutions not only to the problem of providing optimal health care to patients but also as a innovative view of how to solve the layout problem in Innovation Facilities in the New Environment.

5.3.2 Relevance and application to Innovation Facilities

Although diversity is not PA's research interest, PA theory does highlight a possible application for Innovation Facilities. It suggests focusing on dynamic relationships between work and the work environment in the **New Environment** which is characterized by change. Innovation Facilities should adapt to such change by focusing on:

1. The **organizational structure** viewed from technological, economic, and environmental aspects, which will be expressed in terms of the social relationship between knowledge workers';

2. The **adaptation system** provided by architecture as an evolving process facing dynamic challenges in a changeable environment. We shall take the adaptation system as an evolving process in developing the design tool fostering interaction of diverse researchers in a changing environment;

3. The evolving **cluster** design, which represents an integrated set of spatial and organizational solutions to the spatial layout problem in Innovation Facilities.

5.4 Duffy's theory of Office Design

5.4.1 Summary of the theory

Duffy's research for the future intellectual work place, the 'New Office', using office space to support business performance, and different opinions from traditional office design, suggests that: "*Working is changing radically. Office work itself is gradually becoming more and more varied and creative*". Following new changes, there are thus fundamentally two dimensions of improvement in the use of office space for business purposes that are open to management: gaining more *efficiency* and wining more *effectiveness*[4].

In addition, Duffy stresses the importance of communication, collaboration, and group work in the 'new office' and recommends that: "contemporary managerial thinking should be leading …to richer and more diverse office layout…". In addition, Duffy emphasizes the important role of 'face-to-face interaction' in a new office: "*Interaction is the personal, face-to-face contact that is necessary to carry out office tasks. As the amount of interaction increases, there is more pressure to accommodate and support such encounters. Even more pressure is exerted as the quality of interaction increases…interaction can range from the most informal to the most formal meetings…***Interactions that are not face-to-face, i.e. are via the computer, telephone, or other virtual media, are NOT directly significant***, although they are*

[4]Duffy made an interesting comparison between the traditional office and his new office. These two kinds of office are different in their 'Pattern of work', 'Pattern of occupancy of space over time', 'Type of space layout, furniture systems, and use of space and buildings', and 'Use of information technology'. The new office is for 'creative knowledge work', 'interactive work' instead of 'routine processes', and 'isolated work'. The new office is a 'distributed set of work locations linked by networks of communication' and 'multiple shared group work' (Duffy, 1997). However, he has not discussed the possible negative impacts of IT technology in the 'New Office', which Van Alstyne and

likely to supplement, or become a substitute for, face-to-face interaction both now and in the future". Duffy thinks that the traditional organizational mode of the conventional office is 'the office as a factory' which is low in interaction---apart from social chatter---as well as low in the autonomy given to individual office workers. Meanwhile, "*higher-level office activities of this type are being transmuted (re-engineered) into more intellectually demanding activity where working together and teamwork are all important*" (Duffy, 1997).

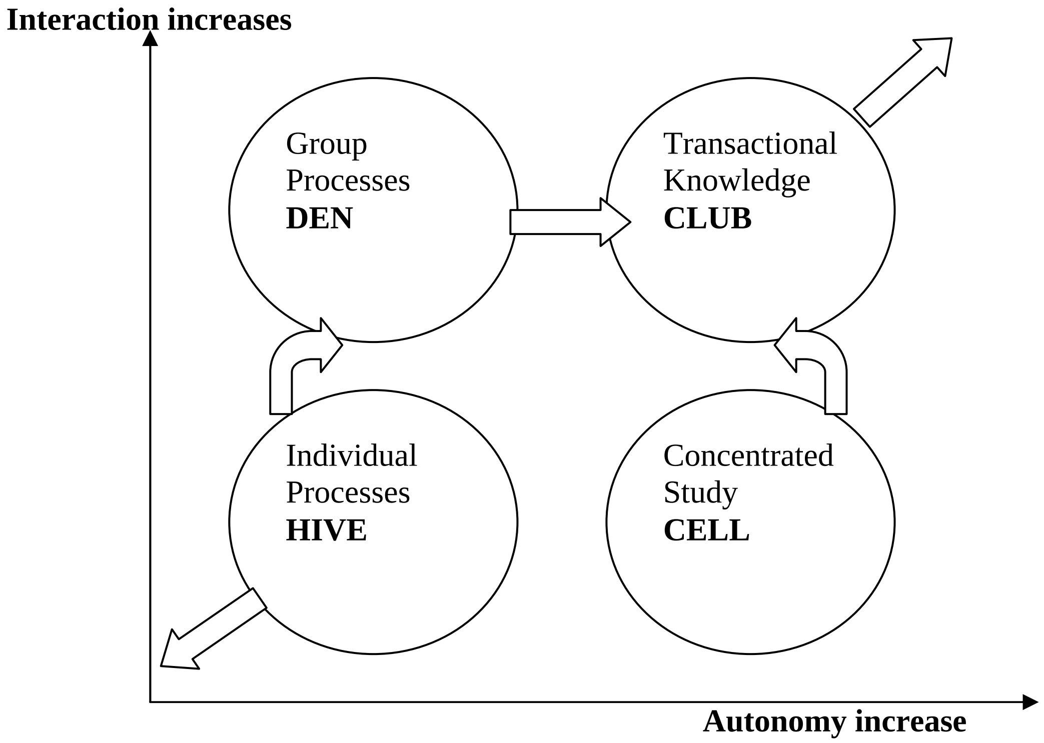


Figure 5.1: Four major organizational types. (source: Duffy, 1997)

Duffy identifies four major organizational types as a shorthand way of capturing the distinct work patterns: hive, cell, den, and club. Duffy further discusses these four modes in different aspects varying from 'Pattern of work', 'Pattern of occupancy of space over time', 'Type of space layout, furniture systems, and use of space and buildings', to 'Use of information technology'.

Duffy believes that: "Innovation in office design, …, seems to be happening most rapidly in innovative organizations in the most innovative sectors of the economy ". Duffy forecasts that: "*Cities are great labor markets as well as places that generate intellectual, business, and social stimuli. The new kinds of activity upon which the economies of the future cities will increasingly depend---media, advertising, the pop industry, and, dare I say, architecture---need the densely interactive infrastructure of the traditional city.* ***Cities suit networkers!***". He has predicted that the main driver for

Brynjolfsson have found.

society would be the knowledge industry, and that the infrastructure must suit the network layout. These two innovative points exactly meet the assumptions in our research. The way of viewing our world as a '*network*' is becoming popular. In later chapters, we will see how buildings and social informational relationships can be represented by networks.

5.4.2 Relevance and application to Innovation Facilities

Duffy's 'New Office' has possible application for Innovation Facilities as follows:

1. 'New Office' has pointed out changes in the New Environment and its increasing demands for a **diverse work environment** for more creative performance, which transfers the 'office as factory' to a location for 'more intellectually demanding activity';

2. 'New Office' proposes a 'distributed set of work locations linked by **networks** of communication' and 'multiple shared **group works',** which outlines the importance of identifying locations connected by a network structure in Innovation Facilities, and group work in terms of 'clusters';

3. 'New Office' stresses **face-to-face interaction** in the New Office, which is extremely important in maintaining long-term sustainable innovation in our research;

4. The way of identifying four major **organizational types** as a shorthand way of capturing the distinct work patterns, is very innovative. These organizational types will be represented by special models to portray information flow in Innovation Facilities.

5.5 Turner and Myerson's theory of New Workspace

5.5.1 Summary of the theory

Turner and Myerson propose the concept of 'New Workspace' which suggests a better understanding between organizational culture and the work environment. They claimed that: "*At the turn of the twentieth century, the world of work in general but of office work in particular is in an state of enormous change and uncertainty*". They believed: "*Technology is crucial to productivity in factories and offices alike. … The Internet is further changing the nature of competition…*" However, the Cyberbalkanization observed by Van Alstyne and Brynjolfsson, has not been discussed. Turner and Myerson's discussion focuses mainly on management, organizational change, and the labor market in office design. They criticize the disadvantage of the traditional organization: "*Large, inflexible, hierarchical organizations are especially vulnerable to change, can no longer guarantee any real job security*". They believe changing the working system can break down barriers in the working environment. Nonetheless, this bridge is still a bridge built by management and social policy instead of architectural design concerns.

They investigate how traditional structures can be rethought and adapted through the reorganization of the workplace and the removal of physical barriers to changes. Four typical and disturbingly familiar work environments are: *Monolith*; *Makeshift*; *Modernizer* and *Mould-breaker*. They argue that: "**Networking** is not just a way of developing useful business contracts outside the organization, it is a **key element of the informal communication channels**—which operate even in the most apparently rigid hierarchical structure—and is the lifeblood of the newer-style freeform organization". Even though the networking here is more concerned with management and organizational values, it points out also the importance of the network in personal relationship in the new work environment. A '**Cross-disciplinary collaboration**' was also advocated by Turner and Myerson. They argue that: "*Within traditional organizations, different disciplines segregate themselves into groupings which are not merely physically isolated in their own areas of the office, but, in communication terms, detached from the demotic tongue of the organization as a whole by individual arcane professional dialects*". This point of view seems to support our assumption that cross-discipline interaction will improve knowledge productivity over the long term.

Turner and Myerson also emphasize the importance of 'closer interaction' in the work environment. They state: "Key features of modern management style are a greater freedom and involvement in the decision-making process for junior staff, and **the closer interaction** with frontline activity of staff from once discrete specialist corporate service disciplines such as finance, marketing and IT." Theses trends are displayed in the development of cross-disciplinary team working. Accordingly, Turner and Myerson introduce six proven workplace layouts: *Town Square; Village neighborhood; City in Miniature; Space-time Machine; The Campaign Room and the Club* as new types of workspace.

In the workplace layout '*City in Miniature*', the 'diversity' issue was addressed. Turner and Myerson state that: "*In the city, lots of different things are going on all the time. People make different choices all the time and are not bound by the repetitive, monotonous limitations of their environment. That dynamic feeling can be replicated in the out-of-town office, so that work areas are integrated with a library, fitness* *center, crèche, cafes, shops and* ***informal meeting places*** *within a* ***network*** *of streets. Staff can therefore organize their working day as they would a journey through a* ***diverse*** *and stimulating cityscape*". If we read these words carefully, we will find two important ideas inside. First is the amazing function of '**informal meeting places**' in the work environment, which will play a critical role in cultivating innovation in the work environment. The second idea is that they noticed that the one remarkable charm of the cityscape is the concept of 'Diversity'.

In an article in the *Sloan Management Review* of 1984, Schein identifies two different types of organizational culture defined by the physical ambience and social structure of the office: "*In organization A there are open office landscapes, few closed doors, people milling about, intense conversations and arguments, and a general air of informality. In organization B there is a hush in the air. Everyone is in an office with closed doors, nothing is done except by appointment and pre-arranged agenda. When people of different ranks are present there is real deference and obedience. An air of formality permeates everything*". Turner and Myerson believe that in the new environment today, Model A would be the best way to motivate, engage and enthuse all members of an organizational family to mange all possible changes. Model A will motivate social interaction between users, and thus plays an important role in the beginning stage of knowledge production in which communication is crucial. Meanwhile Model B will stress the development of the benefit generated from model A, and therefore plays an important role in later stages of knowledge production, in which concentration is critical. Model A presents concept of 'Community' (Diversity is one reflection of Community) in design and planning; Model B presents concept of 'Privacy' in design and planning. An innovative environment should seek an evolving balance between Model A and Model B, between 'Community' and 'Privacy'. Given more the complex puzzle in a real design situation, there might be more criteria such as 'Diversity', 'Flexibility', 'Security', 'Economy', 'Ability to evolve' etc., and accordingly there would be a Model C, Model D, Model E, etc. Multiple-criteria methods (Shefer and Voogd. 1990) can seek fine compromise between these elusive criteria if these contradictory requirements between them.

5.5.2 Relevance and application to Innovation Facilities

Possible applications of the 'New Workspace' can be expressed in the following points of view:

1. 'New Workspace' proposes a better understanding between **organizational structure** and the work environment, and identifies typical workplace layouts to represent them. It points out the right direction to study organizational structure in Innovation Facilities;

2. In the process, ‘**Networking**’ plays important role in reorganizing the working environment. Again, the importance of the network shows the need to use it in the development of the design tool;

3. In ‘New Workspace’, ‘**Cross-disciplinary collaboration’** seems to be effective for removing organizational barriers, which in our research will be transfered as the concept of ‘diversity’ in an innovation milieu;

4. The importance of creating ‘**informal meeting places**’ for ‘closer interaction’ in an innovation environment is highlighted in ‘New Workspace’, especially in the type of workspace of ‘City in Miniature’. It is important to notice that one remarkable charm of cityscape is the concept of ‘Diversity’.

All these firmly support the basic assumptions in our research.

5.6 Raymond and Cunliffe’s research of Tomorrow’s Office

5.6.1 Summary of the theory

Raymond and Cunliffe’s also observe that Business and IT technology are changing the world. They warn that: “*The workplace is under pressure from powerful forces: 1) Rapid changes in markets and thus in businesses objectives; 2) A continuing flow of new concepts and products in telecommunications and information technology; 3) A stream of ideas on how companies should be organized and run*”. In the Survey report on *BT Workstyle 2000 for Westside,* they argued that: “*The office of the future…should be a social stock exchange of propositions, projects and proposals*”. Raymond and Cunliffe sum up the new changes resulting from the new environment from two aspects: changing of organization; and changing of people. A very important conclusion of theirs it the prediction that tomorrow’s organization will be a structure of a ‘**Network**’ instead of today’s triangular structure of ‘**Teams**’ or yesterday’s Pyramid structure of ‘**Hierarchy**’.

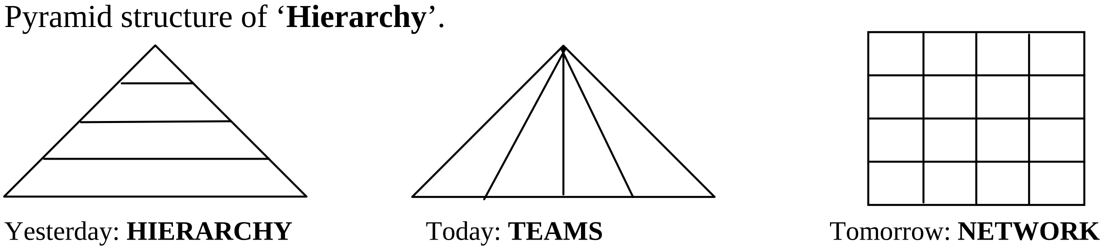


Figure 5.2: the changing of the structure in organizations. (Source: Raymond and Cunliffe, 1997)

Raymond and Cunliffe categorize four types of organizational models of office: Centralized; Decentralized; Mobile; and ‘Third-party site’. Concepts of the office in history are in many cases remarkably up to date: Monastery; Palace; Palazzo; Market; Confessional; Tent; Factory; Landscape. They predict tomorrow’s office as having 8 types: Laboratory; College; Club; Hotel; Shopping Centre; Control Centre; Oasis;

Village Street. These models are suggested to help us rethink the workplace, and seek suitable design solutions to adapt to changes in the New Environment.

However, building structures seem to lag behind the changes in organizational structure. They observe two interesting places in BT. The first they call a 'typical work station cluster in open office areas'; the second is the Café spilling out into the central atrium. The latter spaces are used all day for informal meetings between diverse workers. But in the former type of location the chance of interaction is very low[5]. They conclude that traditional offices are designed around the movement patterns of the first two structures shown in figure 5.2, but that with the rapid increase in information technology, the pattern is moving toward the third structure, around 'Information' and 'Knowledge' in a network structure.

To identify 'Patterns of Movement', Raymond and Cunliffe suggest that the functional and psychological needs of movement are interwoven, and are best looked at together, as are the needs of the individual and of the organization. There are three types of pattern of movement: Star, Grid, and Ring. They evaluate both the advantages and the disadvantages of these three basic patterns of movement (These might be called 'Prototypes'). These can be summed up in the table below.

[5]The investigation show that in BT (British Telecom Westside), 94% of the employees use E-mail regularly as communication means; 77% of the employees use Voice mail every day; 30% of the employees use Videoconference regularly. They observe that: "The 'virtual team', the 'virtual office' and the 'virtual organization' are feasible, exciting---and exist. But they lack humanity. People need environments with a feeling of well-being". As one component of humanity and well being, physical diverse social interaction is a key point, just as Turner and Myerson identified in the 'City in Miniature'. Raymond and Cunliffe measured the percentage of time one manager spent doing things in a whole year. 25% of time was spent on Documents (writing and reading); 16% on Voice (speaking on the phone); 12% on non-communication (business travel, analysis, production, etc); 15% on formal meetings; and 32% in informal meetings. It seems that this manager spent less time on Virtual Interaction and thus had more Physical Meetings in his schedule, which was different from his colleagues. But they have not investigated what may cause a higher or lower percentage of informal meeting, which might be constrained by architectural topology and typology. This will be our emphasis in the research. They argue that communication in and out of the office, and communication within it are different. People, paper, other objects and information move through the work environment.

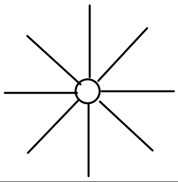
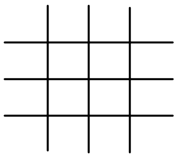
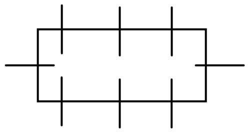
Pattern of Movement	Star 	Grid 	Ring 
Characteristics	Centralized; Major meeting point at the center; No-integrating	Decentralized; Integrating	Peripheral; Choice of two ways around; Ring itself is a linear 'meeting zone'; Semi-integrating; If combined with several links between floors, takes on some of the characteristics of the grid pattern
Advantages	Orientation good; Access good at the center; Easy to control and make secure	Access equally good everywhere; Multiplicity of routes; Variety of meeting points	Orientation reasonable; Access moderately good everywhere; Relatively easy to control and secure
Disadvantages	Access bad at the periphery; Only one choice of route; Isolating	Orientation poor; Hard to control and make security	

Table 5.1: Three types of patterns of movement (Source: Raymond and Cunliffe, 1997)

Raymond and Cunliffe have focused on patterns of movement relating to typology and topology constraints, although they did not relate building networks and social networks, in the way that is the subject of our research. They investigated three patterns, but these three basic types have not been simplified into the simplest 'Prototypes' which will be very important in our research.

Raymond and Cunliffe further extend the patterns of movement to thinking of circulation in the work place. They suggest that: "*The circulation routes in a particular workplace are related to who needs o be near what and, as importantly, to what links are not needed---for circulation is usually seen as a waste of space*". To address this, they further suggest: "*Maximum movement should be channelled along the primary routes, with major facilities and 'magnets' relating clearly to them*". They propose these to be studied in bubble diagrams as architects usually do in design practice. But they have not clarified what mechanism can be used to visualize and control the desired performance, such as '*interaction of diverse researchers'*, for instance. They also list other criteria that need to be considered: mobility, safety, and security. They even address the possible internal dilemma between a pair of criteria. They point out: "*The movement needs of safety and security are largely conflicting* ". Safety requires escaping as soon as possible when a fire or accident occurs, hence is to do with promoting movement. But security on the other hand is to do with restricting movement. They have not concluded how to solve the conflict.

Raymond and Cunliffe categorize ‘Psychological needs’ to include: 1) Interaction; 2) Proximity; 3) Stimulation, distraction and peace; 4) Privacy and Confidentiality; 5) Security; 6) Territoriality; and 7) Status and image. Raymond and Cunliffe thus emphasize physical interaction among employees and its profound significance for the innovative workplace. They identified modes of activities as follows: Solo Activities; Group Activities; Congenial Activities; and Social Activities. Interactions between employees may occur in more than one of these four modes. Raymond and Cunliffe claim that: “*Socializing is a major element in modern work processes, and designing for it to be effective is critical to business success. Social activities not only keep the customer and the worker happy, but encourage the invaluable exchange of ideas*”. Fundamentally, Raymond and Cunliffe claim that: “Interaction between individuals and groups is becoming more important all the time. At the operational level, activities are integrated with each other; at a creative level, **interaction breeds innovation**; at an organizational level it compensates for dispersed working; and informally it provides the medium for that vital system of business communications --- office gossip. At the same time, unnecessary interaction can be expensive and time consuming.” Raymond and Cunliffe further point out the importance of ‘Proximity’ and its relationship with ‘Interaction’: “*Proximity and interaction are two sides of a coin. Although telephone, E-mail and video-conferencing are reducing the need to meet face to face, spending time together is still the foundation of working relationship. Proximity makes this easier; so easy activity needs to be near the other activities with which human links are important.*” They conclude that: “The design implications of proximity include **space allocation and distribution**, **circulation routes**, security and control, and the image such relationships can convey to staff and customers ”. In later chapters, we will see how to make different spatial allocations, and different circulation routes taking account of topological and typological constraints[6].

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[6]Raymond and Cunliffe identify six types of space in the workplace: Primary Space; Ancillary Space; Support Space; Social Space; Service Space; and Circulation Space. Social Spaces are defined as: “ones in the office that people use for activities largely unconnected with work: the cafeteria, the gym, the clubroom or the creche”. The function of Social spaces has been recognized by Raymond and Cunliffe, but has not been investigated in the context of a network structure of building and society.

Raymond and Cunliffe also investigate ‘Ambience’. Creativity is essential for the competitive company. Raymond and Cunliffe argue that the creative workplace should make worker and visitor alike feel: 1) at home, comfortable; 2) confident, sure of their individual identity and of their worth as a human being; 3) safe, knowing that they can share without losing out, and can take risks without retribution; 4) in control of their destiny, and a partner in an endeavour; 5) responsible for the good of themselves and towards those they work with; and 6) creative and innovative.

Ambience should not be created by default. It has both physical aspects (accessibility; the senses, color), and psychosocial aspects (status, personalization, privacy, feng-shui, and good manners). Here we realize that Raymond and Cunliffe have listed ‘Privacy’, but ‘Diversity’ is not included. They also

Raymond and Cunliffe also mention the innovative research of Professor William Hillier and Alan Penn, on ‘spatial integration’, which is a key factor in determining ‘communication networks that develop within a workplace. All them believe: “**these networks foster an innovative and entrepreneurial atmosphere**. ” Hillier and Penn’s research developed computer programs to predict whether a building will be easily understood and intelligible to move around in. Their research also includes how interactive a particular space will be, the clarity of the circulation routes and whether facilities are correctly placed.

5.6.2 Relevance and application to Innovation Facilities

Raymond and Cunliffe’s research fundamentally highlights many important possibilities in developing our research:

1. The office of the future will face challenging changes in the New Environment, in which **organizational structure is reshaped**, and in which physical interaction of diverse researchers breeds creativity in the work milieu;

2. The increasing **virtual means** adopted in the work milieu do improve remote personal contacts, however also potentially decrease **face-to-face interaction** among diverse researchers, which is identified as ‘Cyberbalkanization’. The advantages from both virtual and face to face contacts have to be combined together;

3. To adjust to the new organizational structure and new problems in the New Environment, building design needs to be concerned with several aspects: 1) **Spatial Proximity**: space allocation and distribution; and 2) **Network control**: circulation routes;

4. The idea of **basic models** of organization can be used in developing ‘basic models’ of building typology on the basis of different topological characteristics, which can be identified as ‘prototypes’ in design generation;

5. Taking ‘diversity’ as one aspect of ‘**Psychological needs** ’, there are still many other aspects mentioned by Raymond and Cunliffe, which include: 1) Interaction; 2) Proximity; 3) Stimulation, distraction and peace; 4) Privacy and Confidentiality; 5) Security; 6) Territoriality; 7) Status and image. It is highly possible that there may be internal conflicts between these ‘Psychological needs ’ in design, and so a multiple-criteria method is hence suggested;

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introduced ‘sustainability’ in Ambience, but it was related to ‘Green Issues’ that affected ambience instead of ‘Interaction of diverse researchers’ that will promote sustainable innovation in ambience.

6. The creative work milieu is a general system which should including a sense of being: 1) At home, comfortable; 2) Confident, sure of their individual identity and of their worth as a human being; 3) Safe, knowing that they can share without losing out, and can take risks without retribution; 4) In control of their destiny, and a partner in an endeavour; 5) Responsible for the good of themselves and towards those they work with; 6) Creative and innovative. The spatial developments for these psychological senses need to be investigated.

5.7 Hillier, Penn, Desyllas and Vaughan's 'Space of Innovation'

5.7.1 Summary of the theory

Hillier, Penn, Desyllas, and Vaughan also refer to the changes in the New Environment, in which the most prominent are 'organizational change' and 'new technologies'. They propose a new system called 'Space of Innovation' to help generate new organizational structures and facilitating individual communication. They claim that, work organisations are undergoing profound and rapid change, which are driven partly by changes in technology, coupled to the globalization of markets and business processes, and partly by the changing lifestyles and aspirations of the workforce.

They suggest a possible spatial deign theory to facilitate or host innovation. They point out that, innovation and the management of innovation were largely seen as goal-oriented processes in which strategic management and planning should play a crucial role. The task of management was essentially one of deciding on goals and then planning the provision of resources---human, physical, and informational --- to reach those goals. Penn, Desyllas, and Vaughan believe that: "*the critical information leading to genuine innovations came from outside the work group*". They cite Allen's view that: "t**he inner team cannot sustain itself without constantly importing new information from the outside world**…such information is best obtained from colleagues within the organization" (Allen, 1977). This supports our current research which considers that information from outside can be largely obtained via the 'interaction of diverse researchers', which involves as different as possible agents from outside of the mono-team. However, this can only be effectively done by an internal network in which most nodes can obtain information from outside.

The fashion in work environment is currently turning to the network or 'N-form' organization and 'virtual companies' as structures which use the new communications technologies to allow rapid response to a changing work environment. Nevertheless, Penn, Desyllas and Vaughan argue: “*However, each of these is essentially an organisational form proposed in isolation from the particular nature of an organization’s work process, the effects of the spatial organisation of work, and the design of its workplace.* ” Penn, Desyllas, Vaughan note: “*Still it seems that the realisation of new organisational forms, and in particular their spatial realisation, is being driven by practice rather than theory*”. Consequently, Hillier’s research in spatial syntax is very constructive. He investigates work environments in research laboratories, and finds evidence that “*the pattern of space in building interiors affects patterns of ‘useful’ interactions between research groups* ” (Hillier et al, 1990; Hillier and Penn, 1991; Penn and Hillier, 1992).

Patterns of Space → Patterns of Movements → Patterns of ‘useful’ Interactions

Figure 5.3: The logic chain between patterns of ‘space’, ‘movements’ and ‘interaction’

The main discovery of Hillier’s research is that: “*the mean integration of an area of a building, say a floor or a wing, was related to the mean degree to which staff located in that area were found ‘useful in their work’ by people from other research groups*”. For the purpose of our research we consider the definition ‘*useful to their work*’, to include informal interactions, when two knowledge producers from different disciplines meet each other by chance, as well as formal ones.

The mechanism suggested by Hillier and his associates was that “spatial patterns affect movement patterns and that movement patterns bring people past other people’s workstations”. This contention is supported by an analysis of the relationship between patterns of local movement within a research group area, global movement around the building as a whole, and the location of interaction within the laboratory. Hillier and Grajewski conclude: “occupation density and mean spatial integration to be the two main factors determining observed levels of interaction in office environments. … people in more segregated locations within the work environment move more than those in more integrated locations” (Grajewski 1992, Hillier and Grajewski, 1987).

Penn, Desyllas, and Vaughan concluded that: “These findings give rise to a simple theory of how building design might in principle be held to relate to organisational function through the construction of the **‘local to global’ interface**. In particular, the pattern of useful work-related interaction between groups, which Allen had found to be critical to innovation, appears to rely on this interface”. Penn, Desyllas and Vaughan examine two research led projects, company X and company Y. Work organizations were investigated from the aspects of being a means both of facilitating individual creativity, and of bringing maximum leverage to bear from the disposition of the organization’s resources. They suggest possible detailed mechanisms through which the spatial design of the work environment might be implicated in pursuing 'Innovation'.

In these two cases, they visualized the patterns of movements and observed the interactions between these movements. They identified different activities when these interactions occurred. They conclude that "*At one level, unplanned interaction provides the main resource for rapid transfer of ideas and formation of flexible working groups. This depends on shallowness and access and the interface between movement and general work. At the opposite extreme, where it comes to execution of a set of tasks, programmed meetings and individual work both require the reduction of interruptions to a minimum*". They conclude that " *the spatial integration alone may be insufficient to support flexible working and that spatial differentiation is necessary to provide the range of environments needed by different types of work activity*". Moreover, they advocated a possibility of providing both 'Privacy' and 'Community'. Here, we suggest one more criterion, 'Diversity' to fix the insufficiency in spatial integration.

In our own research, the research target as 'Innovation' is similar to their 'Innovation Space'. However, the research route is somewhat different. It is to cultivate the 'interaction of diverse researchers' by studying the topological and typological aspects involved.

5.7.2 Relevance and application to Innovation Facilities

Possible applications from 'Innovation Space' to our theory of the construction of 'Innovation Facilities' may be as follows:

1. Hillier, Penn, Desyllas and Vaughan's theory focuses on innovation in space; a goal-oriented process between **inner organization and external organization** seems to be critical in promoting diversity for long-term innovation, since the inner team cannot sustain itself without constantly importing new information from the outside world. However only inner teamwork can focus on the detail. In particular, the pattern of useful work-related interaction between groups appears to rely on the interface from **'local to global'**;

2. **Occupation density** and **spatial integration** are the two main factors determining the observed levels of interaction in innovative environments; Occupation density can be represented by '**clusters**'; Spatial integration can be represented in a means-ends chain: Patterns of Space; Patterns of Movements; Patterns of 'useful' Interactions. Both patterns of space and patterns of movements are constrained by the network structure of **building circulation topology** which will be investigated in our proposed design tool;

3. At one level, unplanned interaction provides the main resource for the rapid transfer of ideas and formation of flexible working groups. This depends on shallowness and access and the interface between movement and general work. At the opposite extreme, where it comes to the execution of a set of tasks, programmed meetings and individual work both require the reduction of interruptions to a minimal level. Therefore an **adaptive balance between informal and formal**, community and privacy is crucial. Here again we need a **multiple-criteria** method.

5.8 Tzonis and Chermayeff's Advanced Research at Yale

5.8.1 Summary of the theory

Chermayeff and Tzonis's (1967) advanced research at Yale also addressed important design methodology focusing on campus design, which was based on a number of important basic assumptions:

1. **Social intercourse** is an important ingredient in human evolution;
2. **Face-to-face urban concourse** at different scales is an important part of social intercourse;
3. A New Urbanism is a compound of **diverse** communication systems and confrontation; exploration and adventure of first hand experiences;
4. The **complexity** of the new urbanism requires reorganization in the front of Dynamic Order: interaction between many functions and components structured hierarchically; in spectra of scale and character
5. This complexity operates in a system governed by **urban parameters,** which are constant principles irrespective of location in time and space, but which can, however, accommodate variables of geography, climate, culture and technology;
6. A model of such a system may be thought of as an organization of **Flow sub-systems** (serving components), systems of distribution and disposal operating in fields and territories measured by time/distance/frequency, and Container sub-systems (inhabited places) operating as territories and spaces functionally defined, and human concourse places sociologically defined, measured by intensity/density/occupancy;

7. An urban model of interaction between these may be organized in three major systems: **Inter-urban; Intra-urban; Supra-urban**;

8. The urban system as a whole may be represented by a model based on a complex hierarchical order of related (complementary) functions organized in **hierarchies and a spectrum** between extremes, first appearing as contradictions but which may be translated into complementarities with intermediate quantities and qualities in the same spectrum; (Chermayeff and Tzonis, 1967) [7]

To visualize the organization underlying the urban structure, the study developed a system of representation, basically topological, of '*floor systems*' and '*container systems*'. The container systems were further categorized into 'targets' and 'exchanges'. A system of graphical symbols was developed to represent cases according to the concepts of the model[8]:

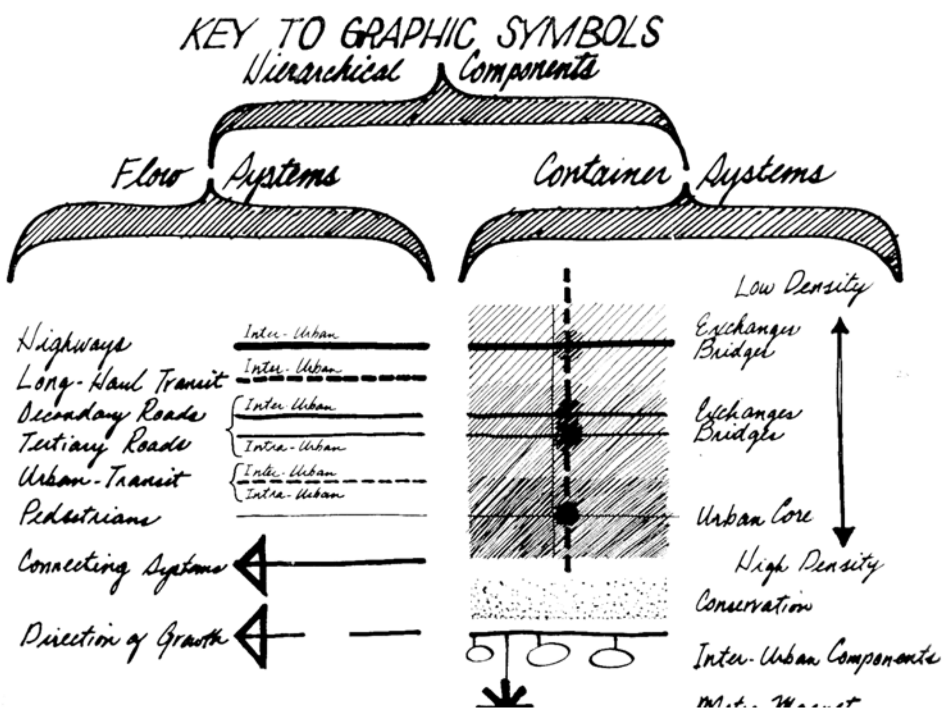


Figure 5.4: Key to graphical symbols (source: Tzonis and Chermayeff, 1967).

[7]In order to stimulate and develop such a theory, a number of 'Urban Models' that is cases, were selected, at various scales and in different locations which had a common theory (social purpose), organizational principle and quantitative data sufficient for comparative analysis, and at the same time, proposals which suggested no new theoretical basis for their form or were theories of so high an abstraction that they appeared incapable of being translated into tools for model building. The whole research was offered as a prototype analytical tool, albeit imperfect, and as a guide towards understanding urban issues which might be considered as constant parameters in an industrializing world (now, it is an information world).
[8]In Tzonis's later research in the 1980s, this system was developed into a more abstract M-O-P system (Morphology-Operation-Performance) which will play an important part in our design tool.

Such a system-structuring device can employ both verbal and graphical means of clarification. Ideally it would employ cinematic techniques, since dynamic order (interaction) is best visualized through a dynamic medium. The various pieces of all environmental problems may thus be plotted in **Appropriate Categories of Parameters**: be assigned to their **Appropriate Level of Abstraction** and proper place in the **Design Process**. This structuring (plotting) process may in its turn be facilitated by a grid in which all the aspects of the problem may be combined and made visible in an ordered way, in a pattern[9].

Chermayeff and Tzonis's theory provides us a very important framework to develop our own system in solving problems in 'Sustainable Innovation Facilities' for the following reasons:

5.8.2 Relevance and application to Innovation Facilities

1. Social interaction in terms of Face-to-face urban concourse is stressed as crucial in an urban system with many urban parameters including 'diversity' of interacting groups as well as 'non-scheduled, random encounters';

2. The urban system as a whole may be represented by a means-ends model of hierarchical order of related (complementary) functions;

3. A model of such a system may be thought of as an organization of two types of components: flows and containers. The relation between these components is subject to topological constraints.

[9]This system can be described in the table below:

Ends Goals	Purpose Principles Strategy	Theory Commitment	
Organizing Principles	Characteristics Operation Tactics	Methodology	Operational Components
Organizing Specifics	Environment Place Use	Operational Tools	Empirical Knowledge Field Research Systems Systems Analysis
Components Means	Functional Physical	Social Technical	Hierarchies Model

Table 5.2: The structure of Chermayeff and Tzonis's system (Source: Chermayeff and Tzonis, 1967)
The three major groups of Parameters may be categorized as: 1) Bio-social ends; 2) Organizational principles and organizational specifics; 3) Functional components and physical components.

5.9 Jacobs's Theory of Diversity in Urban Space

5.9.1 Summary of the theory

While all the discussions above focus on how to design Innovation Facilities, few of them focus directly on diversity in Innovation Facilities. On the other hand, Jacobs discussed carefully the issue of diversity in urban space half a century ago, but she was not concerned with Innovation Facilities at that time. Jacobs emphasized the importance of diversity in urban space and the necessary physical conditions to create diversity in urban space. The knowledge in Jacob's theory can also help us thinking about how to promote diversity in Innovation Facilities by design means. In her significant work "*The Death and Life of Great American Cities*" Jacobs suggests 4 basic conditions to construct diversity in urban design (Jacobs, 1961):

Condition 1 (multiple function-schedules-purposes): The district, and indeed as many of its internal parts as possible, must serve more than one primary function, preferably more than two. These must ensure the presence of people who go outdoors on different schedules and are in a place for different purposes, but who are able to use many facilities in common.

Condition 2 (short distance): Most blocks must be small, that is the occurrence of different streets and the opportunities to turn corners must be frequent.

Condition 3 (Mingling buildings): The district must include a mix of buildings that vary in age and condition, including a good proportion of old ones.

Condition 4 (density for concentration): The district must have a sufficiently dense concentration of people, for whatever purpose they may be there. This includes people there because of residence.

5.9.2 Relevance and application to Innovation Facilities

The most important aspects of Jacobs's theory for the purpose of this research are her investigation and findings about the role of diversity in the urban environment, which can be accordingly transferred to Innovation Facilities as follows:

Condition 1 (multiple function-schedules-purposes): The Innovation Facility, and indeed as many of its internal parts as possible, must serve more than one primary function, preferably more than two. These must ensure the presence of researchers who go out their offices on different schedules and are in the same place for different purposes, but who are able to use many facilities in common. This condition highlights the necessity to design Innovation Facilities with some kinds of topological constraints which can formally or informally create chances for researchers to meet each other. (It is necessary to develop models to represent the topological potential of urban and architectural constraints.)

Condition 2 (short distance for *internal diversity*): Most zones must be small enough to let knowledge workers meet together, that is, routes and opportunities to turn corners must be frequent. (This can be seen as the need to develop micro-topological constraints inside Innovation Facilities to create more chances to meet in order to promote *internal diversity*.)

Condition 3 (Mingling faculties for *external diversity*): The Innovation Facilities must mix different faculties together. (This can be seen as the need to develop macro-topological constraints among faculties in Innovation Facilities, to create more chances to meet in order to promote *external diversity*.)

Condition 4 (density for concentration): The campus must have a sufficiently dense concentration of knowledge workers, for whatever purpose they may be there. (This is consistent with one of the necessary conditions for forming a cluster, Physical proximity, which will be studied in the next chapter).

5.10 Comparison and conclusion

We have now comprehensively reviewed 9 main existing theories relating to Innovation Facilities. They have a similar research target, 'Innovation Facilities', but offer different approaches to the target. Their research targets and methods can be summarized in the following table:

Theory number **Details**	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	**5.6**	**5.7**	**5.8**	**5.9**
Date	1968	1992	1999	1997	1998	1997	1999	1967	1961
Key Concept	People	Placemaking	Process Architecture	New Office	Management	Interior	innovation space	System	Diversity
Innovation Discussed?			Yes	Yes		Yes	Yes	Yes	
Diversity Discussed?						Yes			Yes
Campus Land Uses Discussed?	Yes	Yes							
Building Location Discussed?	Yes	Yes						Yes	Yes
Building Materials Discussed?		Yes				Yes			
Building Style Discussed?		Yes				Yes			
Building Interior Discussed?		Yes				Yes			
Circulation Networks Discussed?	Yes	Yes				Yes	Yes	Yes	Yes
Landmark Discussed?		Yes							

Theory number **Details**	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	**5.6**	**5.7**	**5.8**	**5.9**
Landscape Discussed?		Yes				Yes			
Typology Discussed?	Yes		Yes	Yes		Yes		Yes	
Topology Discussed?									
People Discussed?	Yes			Yes	Yes	Yes	Yes	Yes	Yes
Activity Discussed?	Yes			Yes		Yes	Yes	Yes	Yes
Time Discussed?	Yes			Yes			Yes		Yes
Space Discussed?	Yes			Yes		Yes	Yes	Yes	Yes
Organization Structure Discussed?			Yes	Yes	Yes	Yes	Yes	Yes	
Technology Discussed?			Yes	Yes		Yes	Yes		
Finance Discussed?	Yes		Yes	Yes	Yes				
Cluster Discussed?			Yes					Yes	
Tools Used?			Yes					Yes	
Efficiency and effectiveness Discussed?	Yes			Yes	Yes				
Interaction stressed?				Yes		Yes	Yes	Yes	Yes
Mode Discussed	Yes			Yes		Yes		Yes	

Table 5.3: a comparison between different existing theories

The following conclusions can be drawn from state-of-art theories about facilities related to knowledge production:

1. There is no existing design method to control diversity of physical interactions which can be applied to Innovation Facilities. It is therefore very urgent to develop such a design tool;

2. Almost all existing theories were involved with the enhancement of physical face-to-face social interaction in the built environment, which cannot be replaced by any virtual means;

3. Almost all existing theories suggest that physical face-to-face interaction is constrained by the circulation topology of building complexes and the location of places of interaction in such networks;

4. Graphical means provide a useful abstract tool to visualize <u>operations</u> carried out by groups within the confines of built <u>form</u>.

We can now suggest the following criteria to direct the development of the design tool:

1. The tool must be able to represent and identify differences between social agents (especially information transferring networks) in Innovation Facilities and thus indicate the diversity of an interaction cluster (This will be investigated in Chapter 6: Sociogram);

2. The tool must be able to represent and investigate the allocation, and the topological and typological layout of Innovation Facilities. (This will be investigated in Chapter 7: Archigraph);

3. There must be a systematic procedure by which, given information about difference between groups, a scheme can be generated which accounts for clusters of high diversity.

In the next chapter we will first study the model representing differences between social agents in Innovation Facilities.

CHAPTER 6

REPRESENTING SOCIAL AND INFORMATION FLOW RELATIONSHIPS: THE SOCIOGRAM

Study of the first model for use in the design tool

In the previous chapter, we reviewed existing theories of Innovation Facilities to identify criteria of adequacy for a new design tool to aid the conception of facilities to produce new knowledge in a sustainable manner. Towards this goal, two models will be developed: the Sociogram and the Archigraph. While the first represents social and information flow relationships between individuals or groups in an organization, the second represents the spatial accessibility relationships between the locations in which these individuals or groups operate. This chapter will study the first model used in the design tool.

6.1 The concept of the Sociogram

There are many ways to define and measure the diversity of people, individuals or groups. One of these is to see how far apart they are in terms of their position in a formal organization. This definition fits our objective of developing a tool that controls the diversity of groups in a cluster, the assumption being that the closer they are in an organization the less 'apart', (thus different, or diverse) they are. To represent this distance we will use an already existing tool: the Sociogram.

6.1.1 What is a Sociogram?

The Sociogram is a mode of representation first developed by Moreno and Jennings in the early 1930s, and marked the beginning of the study of sociometry. Moreno defined sociometry *as "…the measurement of interpersonal relations in small groups..."* and the Sociogram *as "…a picture in which people or more generally, any social units are represented as points in two-dimensional space, and relationships* *among pairs of people are represented by lines linking the corresponding points"* (Moreno 1953). Latterly, the Sociogram has been widely used in Sociology, Education Psychology[1], Clinical Assignment and some other disciplines to identify relationships between members of a special group.

6.1.2 What is the application of the Sociogram?

The application of the Sociogram varies in different disciplines within different contexts and research interests. For instance, in education research, the Sociogram can be useful in a number of ways. Social isolationists (those not selected by others) could be placed in interaction with accepting peers or could be made the center of attention in positions such as charades leader or team captain. Those who are negative perceived by others could be provided with training in social skills. By developing good rapport with class members, a student leader could be more influential in convincing them of the need to comply with directions. Additionally, interaction and friendship changes, and a student's progress in becoming more accepted by others can be monitored via frequent administration of the Sociogram technique. In sociology it has a special application. For example, to eliminate a political organization, its rival may first analyze the relationships between members in the organization. A Sociogram can be drawn according to the communications among members. The member with the highest density of connections with the others will be identified as the 'hub' in the Sociogram, and will become the target of the possible ongoing character assassination. By 'removing' just this 'hub', instead of all members in the organization network, the whole organization will collapse and will find it very hard to recover. A similar approach is used in the control of contagion and in the diffusion of innovation. In the first situation (contagion) the aim is to identify the 'hub' in the Sociogram and isolate his/her connections. However in the second situation (innovation diffusion) the process is reversed. The aim is to intensify the hub's connections, and so to increase the rate of innovation diffusion. As another example, to minimize the cost of blocking the spread of AIDS, it is better to identify the 'hub'

[1] In Education Psychology, it is defined that: A Sociogram is a charting of the inter-relationships within a group. Its purpose is to discover group structure: i.e., the basic "network" of friendship patterns and sub-group organization. The relations of any one child to the group as a whole are another type of information which can be derived from a Sociogram. A Sociogram's value to a teacher is in its potential for developing greater understanding of group behavior so that he/she may operate more wisely in-group management and curriculum development (Newcomb, Bukowski and Pattee, 1993). In this case, a Sociogram is a teacher-made device that is used to provide additional information regarding a student and how s/he interacts with peers. Sociogram is hence a valuable tool for determining how a student is viewed by his/her classmates. It assesses interaction and social perceptions using both negatively and positively worded statements or questions. The results are then tabulated to determine how many times each student was chosen and by whom. This information is graphically plotted to identify social isolates, popular students, disliked youngsters, and changes in interaction patterns over time.

in the network of sexual interaction or drug abuse, and to isolate or treat this 'hub' so as to reduce the total cost of treating every node in the network. Even terrorists know how to similarly use the hub in the diagram network of urban society (which will be developed in another model in a later part of this research to represent a network of architecture and urban space). They identified hubs in the urban network of the USA and chose New York, and Washington DC as hubs to be attacked on 9/11. In New York City they identified the World Trade center as the appropriate hub to magnify the consequences of their attack.

6.1.3 How to construct a Sociogram?

Sociograms may be constructed in different ways. For instance, in Educational Psychology, to chart a Sociogram in a classroom, 7 steps are required (Newcomb, Bukowski and Pattee, 1993)[2]. The different targets of research in different domains may result in different ways to construct a Sociogram, but in principle they are the same. They all represent some kind of social relationship by means of a network of

[2] These steps include: 1.Devise a question; 2.Have students write their answers to your question or statement; 3.On a listing of the names of your students, write next to each student's name the number of times s/he was selected by another (tally the responses); 4.Make a large diagram of concentric rings; have one more ring than the greatest number of times any student was chosen. Start outside the last ring and number the spaces from the outside toward the inside starting with "zero"; 5.Write each student's name inside the ring space corresponding to the number of times s/he was chosen; 6.Draw arrows from each student to the student selected by them; 7.Survey the diagram to assess popularity and interaction preferences. This information should remain confidential.

When these steps are implemented, a final Sociogram can be drawn, in which there will be 4 kinds of arrows to show different linkages: 1st choice; 2nd choice; 3rd choice; mutual choice. When we construct a Sociogram in an Innovation Facility, the focus is simply on whether or not there is a link, and the weight of the links is therefore not addressed in the current research. One of the final diagrams in the study showed subtle social relationships in so small a classroom. (Squares represent males; circles represent females).

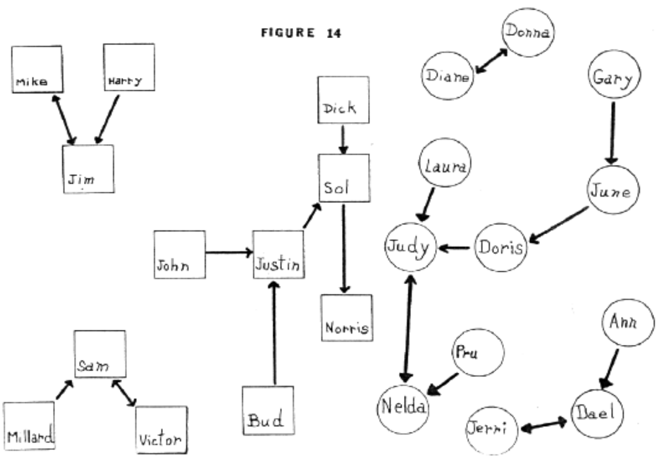


Figure 6.1: A Sociogram (source: A. F. Newcomb, W.M. Bukowski, & L. Pattee, 1993)

nodes and links. The common ways to construct a Sociogram are: 1) identify the target of research; 2) design a questionnaire to detect the performance of the research target; 3) investigation and collection; 4) decide what shall be represented as a node and what shall be a link; and 5) Draw the network-like diagram.

6.1.4 What sort of information can a Sociogram represent?

Depending on the varying interests and purposes of research in different domains, the information represented in a Sociogram can vary, although basically all Sociograms represent some kind of social relationship. For example, in Educational Psychology, the social relationship is represented in terms of friendship among students. In the control of contagion, the chain of the spreading of disease can be represented. In economics, financial flow or business relationships can be represented. The different types of information a Sociogram can represent in different social networks can be compared in a table as shown below:

	Educational Psychology	**Contagion control**	**Innovation Diffusion**	**Political System**	**Economic Market**	**Terrorism Network**	**Innovation Facilities**
What does the **node** represent?	Students	Patients	People	People	People	Terrorist	Researchers
What does the **link** represent?	Friendship	Spread of disease	Innovation	Political relation	Financial relation	Order of action	Information flows and relations for potential new knowledge production

Table 6.1: the varying information Sociogram represent in different social networks.

6.2 The concept of the Sociogram in Innovation Facilities

6.2.1 What is a Sociogram for Innovation Facilities?

Following the previous outline, the Sociogram for Innovation Facilities is defined as a charting of the relationships between individual researchers and groups of researchers in Innovation Facilities, in which researchers, or more generally any units of researchers, are represented as points in two-dimensional space, and in which formal and informal relationships among them are represented by lines linking the corresponding points.

6.2.2 What is the application of the Sociogram in Innovation Facilities?

The purpose of the Sociogram in Innovation Facilities is to identify the academic group structure, that is, the basic "network" of diverse information flow patterns and sub-group organization which will potentially determine knowledge production over the long term. In Innovation Facility, the Sociogram is also a valuable tool for determining how information is passed from researcher to researcher. Generally, the Sociogram in Innovation Facilities has at least two applications: to describe the organizational structure of clusters in Innovation Facilities, which determines the information flow; and to describe the profile of interaction between diverse researchers in clusters in Innovation Facilities.

6.2.3 How should a Sociogram for Innovation Facilities be Constructed?

A Sociogram which represents formal, institutionalized relationsships between members of an organization can be constructed from official rules and regulations stating such relationships. Of this type are the departmental relationships between knowledge specializations, or the relationships for carrying out administrative tasks (e.g. head of department, assistant administrator, secretary etc.). A Sociogram representing informal relationships is more difficult to construct, but it can be acquired through questionnaires or empirical observations. The basic way to construct a Sociogram for Innovation Facilities is proposed as: 1) identify the target of research; 2) design questionnaires to detect the performance of the research target; 3) investigation and collection; 4) determine what kind of researcher(s) shall be represented as node(s) and what kind of relationships between them shall be represented as link(s); 5) draw the network-like diagram.

6.2.4 What sort of information can a Sociogram represent in Innovation Facilities?

In the comparative table above, we illustrated that the Sociogram for Innovation Facilities mainly represents information flows and relationships (in terms of interaction among diverse researchers) that will potentially influence the production of new knowledge. It reveals two basic items of information: the organizational structure of clusters in the Innovation Facilities, which determines the information flow, and the profile of diverse interactions in clusters in the Innovation Facilities.

From the Sociogram, we can ask the following questions: What can one observe through the Sociogram? What kinds of patterns of relationships between people and groups can be depicted, that can guide normative diversity in clusters within a physical facility? To answer these questions, knowledge of the Sociogram is not enough; we have to borrow knowledge from the fields of Social Network Analysis (SNA) and Graph Theory (GT).

6. 3 Social Network Analysis (SNA) for Innovation Facilities

The Sociogram is basically a network that can represent some social relationships among social actors. However it is still not enough to analyze the social relationships it represents. To understand the world of the social relationship represented in the Sociogram, we have to use knowledge from Social Network Analysis (SNA). Wasserman and Faust (1994) systematically introduced the technique of SNA.

SNA is the mapping and measuring of relationships and flows between people, groups, organizations, computers or other information/knowledge processing entities. In SNA, nodes (objects in visual links) represent people, cities, computers, businesses or any other activity or process. The links between the nodes represent interactions of some form: phone calls, e-mail exchanges, conversations, chance meetings on the street, drug or weapon sales - the variety is limitless. SNA provides both a visual and a mathematical analysis of human relationships. The purpose of SNA is to evaluate network nodes, and the relationships between them, from a "human" perspective. In this form of analysis, the significance of nodes is derived from each node's positional relationship to other nodes.

A key precept of SNA is that people tend to interact with people with whom they are already familiar and they tend not to step outside the confines of their known associates. In addition, it is accepted that there is inherent value in the various interactions and relationships. This value is referred to as "Social Capital." In social networks, Social Capital influences interactions within a network. From the viewpoint of SNA, the social environment can thus be expressed as patterns or regularities in relationships among interacting units. SNA provides a precise way of defining important social concepts in Innovation Facilities, a theoretical alternative to the assumption of independent social actors, and a framework for testing theories about structured social relationships in Innovation Facilities.

SNA is inherently an interdisciplinary endeavor. Visual displays including Sociograms and two (or higher) dimensional representations continue to be widely used by network analysis (see Klovdahl 1986; Woelfel, Fink, Serota, Barnett, Holmes, Cody, Saltiel, Marlier, and Gillham 1977). Multi-dimensional spatial representations have proved quite useful for presenting structures of influence among community elites (Laumann and Pappi 1976; Laumann and Knoke 1987), corporate interlocks (Levine 1972), role structures in groups (Breiger, Boorman, and Arabie 1975; Burt 1976, 1982), and interaction patterns in small groups (Romney and Faust 1982; Freeman and Michaelson 1989).

In a social network, *actors are discrete individuals, corporate, or collective social units*. The defining feature of a tie among actors is that it establishes a linkage between a pair of actors (in a social network). Given the different degrees by which actors may be connected to each other in the social network, types of actors in social network can be categorized as:

1. Dyad: (Taking the dyad as the unit of social network analysis), a dyad consists of a pair of actors and the (possible) tie(s) between them.
2. Triad: Triad is a subset of three actors and the (possible) tie(s) among them.
3. Subgroup: We can define a subgroup of actors as any subset of actors, and all ties among them.
4. Group: A group is the collection of all actors between which ties are to be measured.

The Hierarchical Sequence of the Social Network System is illustrated in the diagram below:

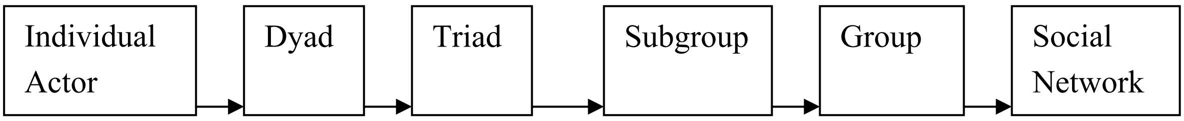


Figure 6.2: Different levels in social network analysis

In our research, the tendency towards 'forming of groups' can be described as 'clustering'. Therefore the dyad, triad, subgroup and group can be seen as 'clusters' on different levels. Attributes of the actors are those Researchers. Attributes of the events are meetings and interactions among researchers.

In SNA, there are several important assumptions:

1. Actors and their actions are viewed as interdependent rather than independent, autonomous units;
2. Relational ties (linkages) between actors are channels for the transfer or "flow" of resources (either material or nonmaterial);
3. Network models focusing on individuals view the network structural environment as providing opportunities for or constraints on individual action;
4. Network models conceptualize structure (social, economic, political, and so forth) as lasting patterns of relationships among actors.

Therefore in an Innovation Facility, if agents are actually connected by any means, the 'flow' of information between them should be observed. This 'flow' of information between agents is constrained by the network structure in the social network. SNA can be more deeply understood by using Graph Theory (GT), a more abstract level of network.

6.4 Graph Theory (GT)

The Graph Theory is a very profound knowledge to study the properties of graph which consist of a set of vertices and a family of lines (possibly oriented) [3]. Here we will only look at several basic concepts which are expected to be used in our design tool in the research.

6.4.1 Meaning of GT in the Sociogram of Innovation Facilities

To understand SNA further, knowledge of Graph Theory (GT) is additionally necessary, because basically, SNA in terms of a Sociogram is a graph in which nodes and links are the basic components. In addition to its utility as a mathematical system, GT gives us a representation of a social network as a model of a social system consisting of a set of actors and the ties between them. By model we mean a simplified representation of a situation that contains some, but not all, of the elements of the situation it represents (Roberts 1976; Hage and Harary 1983). A graph is used to represent actors, and lines connecting the points are used to represent the ties between the actors. A graph g consists of two sets of information: a set of nodes, N= ｛n1,n2,…,ng｝, and a set of lines, L= ｛l1,l2,…,lL｝ between pairs of nodes. There are g nodes and L lines (Harary, 1969).

The only information in the graph is the set of nodes and the presence or absence of lines between each pair of nodes. In SNA, such a diagram is frequently referred to as a Sociogram. In GT, a social network can be studied at several levels: 1) the actor; 2) pair or dyad; 3) triple or triad; 4) subgroup; 5) the group as a whole. In our research, the social network is mainly studied at the level of subgroups, defined as 'clusters'.

The density of a graph is the proportion of possible lines that are actually presented in the graph. A walk is a sequence of nodes and lines starting and ending with nodes, in which each node is incident with the lines following and preceding it in the sequence. The length of a walk is the number of occurrences of lines along it. A graph is *connected* if there is a link between every pair of nodes in the graph. In a connected graph, all pairs of nodes are reachable. If a graph is not connected, then it is *disconnected*. If it is disconnected, then some pairs of people cannot send or receive

[3] The famous problem of the bridges of Königsberg, solved by Euler, is viewed as the first formal result in graph theory. This theory has developed during the second half of the 19th century (with Hamilton, Heawood, Kempe, Kirchhoff, Petersen, Tait), and has boomed since the 1930s (with König, Hall, Kuratowski, Whitney, Erdös, Tutte, Edmonds, Berge, Lovász, Seymour, and many other people). It is clearly related to Algebra, Topology, and other topics from Combinatorics. It applies to -- and gets motivating new problems from -- Computer Science, Operations Research, Game Theory, Decision Theory.

messages from each other using the communication channels[4]. The connected subgraphs in a graph are called *components*. If there is only one component in a graph, the graph is connected. If there is more than one component, the graph is disconnected. In our research we are concerned with whether or not nodes or subgroups (clusters) are connected in chains of information flows in Innovation Facilities.

6.4.2 Geodesic and Eccentricity

A shortest path between two nodes is referred to as a **geodesic**. The geodesic distance or simply the distance between two nodes is defined as the length of a geodesic between them. The eccentricity or association number of a node is the largest geodesic distance between that node and any other node (Harary and Norman 1953; Harary 1969). The diameter of a connected graph is the length of the largest geodesic between any pair of nodes (equivalently, the largest nodal **eccentricity**). Considering a communications network, it is assumed that messages always take the shortest routes (that is, via geodesics). The diameter of a subgraph is the length of the largest geodesic within the subgraph. In Innovation Facilities, Geodesic paths and Eccentricity will be important concepts, since we will use them to identify whether a node is central or peripheral. This will be further explained in the next section.

6.4.3 Centrality and Periphery

Importance, synonymously, prominence and other measures attempt to describe and measure properties of "**actor location**" in an organizational network[5]. We will consider an actor to be prominent if the ties (both direct and indirect) of the actor make the actor particularly visible to be other actors in the network (Knoke and Burt, 1983) (Hubbell 1965) (Friedkin 1991). Knoke and Burt identified the **centrality of an actor.** For a nondirectional relation, a **central actor** is defined as one involved in many ties. The simplest definition of **actor centrality** is that central actors must be the most active in the sense that they have the most ties to other actors in the network or graph. A centrality measure for an individual actor should be the **degree of the node**. Researchers began equating closeness with minimum distance. Centrality is inversely related to distance. As a node grows farther apart in distance from other nodes, its centrality will decrease.

[4] A node, ni, is a cutpoint if the number of components in the graph that contains ni is fewer than the number of components in the subgraph that results from deleting ni from the graph. In a communications network, an actor who is a cutpoint is critical. A bridge is a line such that the graph containing the line has fewer components than the subgraph that is obtained after the line is removed.

[5] Actors who are the most important or the most prominent are usually located in strategic locations within the network. The notion of prestige can only be studied with directed graphs, while centrality can be discussed in both directional and non-directional relations.

Actor centrality measures, reflecting how close an actor is to the other actors in the network, have been developed by Bavelas (1950), and Harary (1959). An actor is **central** if it lies between other actors on their geodesics, implying that to have a large "betweenness" centrality, the actor must be between many of the actors via their geodesics. In our design tool, however, we will merely employ eccentricity as the parameter to measure both centrality and periphery. It is thus assumed that: if a node in the Sociogram has the greatest eccentricity, then it is identified as the peripheral node; if a node in the Sociogram has the least eccentricity, then it is identified as the central node.

6.5 Basic criteria in a Sociogram relating to diversity

Based on all the above theories, we will summarize some important criteria for our research in later chapters. Directly or indirectly, strongly or weakly, these criteria will influence the performance of diversity in Innovation Facilities. We will consider the impact of these basic criteria on diversity in clusters in Innovation Facilities.

6.5.1 Criterion 1 - Connectivity: good or bad for diversity in clusters?

According to Wasserman and Faust (1994) *the connectivity of a graph is a function of whether a graph remains connected when nodes and/or lines are deleted.* The **connectivity** of a graph is a function of whether the graph remains connected when nodes and/or lines are deleted. The point-connectivity or **node-connectivity** of a graph, k(g), is the minimum number k for which the graph has a k-node cut. It is the minimum number of nodes that must be removed to make the graph disconnected, or to leave a trivial graph[6]. The line-connectivity or edge-connectivity of a graph, λ(g), is the minimum number λ for which the graph has a λ-line cut. It is the minimum number of lines that must be removed to make the graph disconnected, or to leave a trivial graph.

In a cluster with high connectivity, it is easy for information to flow through. In such a cluster, the more connections a node has, the more familiar the people are to each other, and the less diverse the people are. Therefore, in a cluster, the higher the connectivity is, the lower the diversity will be.

[6] Four Different Ways that two nodes connected can be: 1) Weakly connected; 2) Unilaterally connected; 3) Strongly connected; 4) Recursively connected.

6.5.2 Criterion 2 - Reachability: good or bad for diversity in clusters?

In a graph a pair of nodes is reachable if there is a path between them. (Wasserman and Faust 1994). In a valued graph, two nodes are reachable at level c if there is a path at level c between them.

In a cluster with high reachability, it is easy for information to flow through. In such a cluster, the more reachable path a node has, the less the diversity of the cluster interacting people form.

6.5.3 Criterion 3 - Robustness: good or bad for diversity in clusters?

Robustness is the property of strength of constitution of a network, that is the degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions. It can be seen as the condition of a product or process design that remains relatively stable, with a minimum of variation, even though factors that influence operations or usage, such as environment and wear, are constantly changing.

In a cluster with high robustness, it is easier to recover the network when it is destroyed or damaged. The connections can be more easily restored in a cluster with higher robustness. This high robustness consequently leads to lower diversity on the basis of the connections reconstructed after being damaged. Therefore, in a cluster, the higher the robustness is, the lower the diversity will be.

6.5.4 Criterion 4 - Betweenness: good or bad for diversity in clusters?

Betweenness is a concept used to evaluate optional routes between nodes in a graph. A node with high betweenness has great influence over what information flows in the network. The more betwenness in a cluster, the higher its robustness. Therefore, in an organizational cluster, the higher the betweenness, the lower the diversity will be.

6.5.5 Criterion 5: Centrality and Periphery (Eccentricity): good or bad for diversity in clusters?

As mentioned, one method of understanding networks and their participants is to evaluate the location of actors in the network. Measuring the network location is to find the centrality of a node. These measures help determine the importance, or prominence, of a node in the network. Network location can be different from the location in the hierarchy, or organizational chart.

Wasserman and Faust (1994) argue that: "*An actor is central if it lies between other actors on their geodesics, implying that to have a large "betweenness" centrality, the actor must be between many of the actors via their geodesics*." He insists that for a nondirectional relation, a central actor shall be defined as one involved in many ties, while a prestigious actor shall be defined as one who is the object of extensive ties, thus focusing solely on the actor as a recipient. Prestige has also been called a status.

The simplest definition of actor centrality is that *"central actors must be the most active in the sense that they have the most ties to other actors in the network or graph."*

As studied in 6.4.2 'Geodesic and Eccentricity', the concept **Eccentricity** is employed to measure both Centrality and Periphery. Eccentricity is defined as follows. Let G be a connected graph and let v be a node of G. The eccentricity e (v) of v is the distance to be a node farthest from v. Thus e (v) = max {d (u, v) : u eV }. The radius r (G) is the minimum eccentricity of the nodes, whereas the diameter d (G) is the maximum eccentricity. Node v is a central node if e (v) = r (G), and the center C (G) is the set of all central nodes. Thus, the center consists of all nodes having minimum eccentricity. Node v is a peripheral node if e (v) = d (G), and the periphery is the set of all such nodes. For a node v, each node at distance e (v) from v is an eccentric node for v.

A highly-centralized cluster has a lower Eccentricity. In such a network, powerful central nodes tightly connect most agents who easily become familiar with each other because of the existence of these central actors. The internal diversity thus declines. On the other hand a peripheral network has a higher Eccentricity, and consequently it has a higher potential for diversity. Therefore, centrality is bad for diversity and periphery is good for diversity, and the higher the Eccentricity, the better it is for diversity.

6.5.6 Criterion 6: Degreesness: good or bad for diversity in clusters?

Social network researchers measure network activity for a node by using the concept of degrees -- the number of direct connections a node has. This corresponds to the local centrality in social network analysis. It measures how important a node is with respect to its nearest neighbors. Common wisdom in personal networks is "the more connections, the better." This is not always so. What really matters is where those connections lead to -- and how they connect the otherwise unconnected! Wasserman and Faust (1994) define this as follows: In a graph, the degree of a node is the number of nodes adjacent to it (equivalently, the number of lines incident with it). The indegree of a node, dI(ni), is the number of nodes that are adjacent to ni. … .Indegree is thus the number of arcs terminating at ni. The outdegree of a node, do(ni), is the number of nodes adjacent from ni. … .Outdegree is thus the number of arcs originating from node ni. The outdegrees are measures of expansiveness and the indegrees are measures of receptivity, or popularity.

In a cluster with high degreeness, it is easy for information to flow through. In such a cluster, the higher degreeness a node has, the less possible it has to contact diverse people. Therefore, in a cluster, the higher the degreness is, the lower the diversity will be.

6.5.7 Criterion 7 - Density: good or bad for diversity in clusters?

Wasserman and Faust (1994) define this as follows: *The density of a graph is the proportion of possible lines that are actually present in the graph.*

In a cluster with high density, it is easy for information to flow through. The higher the density of a cluster, the less able it is to contact diverse people. Therefore, in a cluster, the higher the density, the lower the diversity will be.

6.5.8 Criterion 8 - Transitivity: good or bad for diversity in clusters?

According to Wasserman and Faust (1994): *a relation is transitive if every time that iRj and jRk, then iRk.* The triad involving actors i, j, and k is transitive if whenever i →j and j →k then i →k.

In a cluster with high transitivity, it is easy for information to flow through. The higher transitivity a cluster has, the less able it is to contact diverse people. Therefore, in a cluster, the higher the transitivity, the less the diversity will be.

6.5.9 Comparison of these criteria on diversity

After studying of these important criteria for a Sociogram relating to diversity in clusters, we can summarize them in the table below.

	Connectivity	Reachability	Robustness	Betweenness	Eccentricity	Degreeness	Density	Transitivity
Good for diversity?	No	No	No	No	Yes	No	No	No

Table 6.2: Sum influences of Sociogram criteria to diversity in cluster

Consequently, a normative standard for a higher diversity in a cluster is the bigger social difference between these criteria in Sociogram. To identify such difference and simplify the procedure, it is possible to choose one key criterion to represent the other criteria's performance in influencing diversity in clusters. In the construction of the design tool we will choose the criterion 'Connectivity' as the 'representative criterion' to represent most the rest criteria which might similarly decrease diversity potential. However, difference of 'Eccentricity' shall be counted independently, since it has a potential impact to increase diversity.

6.6 Conclusions

In this chapter we have reviewed important theories to represent social relationship, which include: Sociogram (SM), Social Network Analysis (SNA), Graph Theory (GT), and Sociogram in Innovation Facilities (SI). The most abstract system is actually GT, the second most abstract system is SNA, and the common Sociogram is the third level of abstraction. However SI seems to be the most specific network representation system. These relationships can be represented in a figure below, in which the more peripheral the position, the more abstract and the wider its application is:

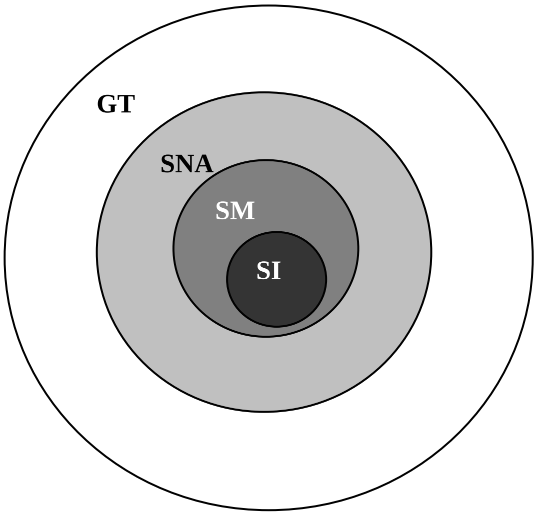


Figure 6.3: Different level of abstract in different represented network

The differences between these representative systems can be summarized in the table below.

	GT	SNA	SM	SI
Only Nodes and Linkages in the System?	Yes			Sometimes
Social criteria used?		Yes	Yes	Yes
What does Node represent?	Something	Social actor	Social actor	Knowledge producer
What does linkage represent?	Connection	Social relationship	Social relationship	Information flow and relations
Label used?		Yes	Yes	Yes
Cluster is discussed		Yes		Yes
Abstract	Highest	Higher	Lower	Lowest
Application	Widest	Wider	Narrower	Specialized

Table 6.3: Differences between different represented networks

The conclusions from this chapter are:

1. There are some existing systems which can represent some organizational relationship among actors;
2. Among these systems the Sociogram is relevant to problems in Innovation Facilities, as an appropriate model to represent the relations and information flow among knowledge workers in a formal organization;

3. The Sociogram can supply information useful to influence diversity in clusters as it can supply a measure of variability or similarity of groups. The assumption in this case is that the closer people or groups are to each other the more familiar and similar they are.

Having suggested the Sociogram as a means to identify diversity of people or groups using information about their accessibility inside a formal organization, we now proceed to see how this information may be used in relation to the structure of accessibility inside the built environment. In other words we will try to develop a way of assigning locations where clusters of high diversity may be formed.

In the next chapter another important model will be developed to construct the design tool for SIF, a model which can represent the structure of accessibility inside the built environment.

CHAPTER 7

REPRESENTING TOPOLOGICAL CONSTRAINTS: THE ARCHIGRAPH

Study of the second model for use in the design tool

In the case study of TUD that we presented in chapter 4, we concluded that the topological structure of a facility is important in constraining the chances of meeting in a building complex. It is therefore important in controlling the diversity of people interacting in a cluster. Having developed a model to represent the degree of difference between interacting people we now turn to the development of a model to represent the topological constraints in architectural plans.

7.1 Ways of representing architectural plans

The topology[1] of space organization of a building complex is often represented using graphs. Graphs contain only two kinds of elements: nodes and links. These resemble the 'container' and 'flow' primitives of the Urban Model described in Chapter 5 and developed in 1962-1966 by Chermayeff and Tzonis. However the representation of graphs is more abstract and suitable for computation if and when needed.

[1] Topology is the study of the various properties of geometric forms that remain invariant under certain transformations such as bending and stretching. These topological properties are based on proximity (contiguity), succession, closure (inside-outside), and continuity. Buildings can be represented topologically by a Poincaré incidence matrix, noting all pairs of locations which are joined by a link. They can also be represented in graphs. The concept of graphs is as simple as it is in electrical systems or chemical structures. It contains only points and links. Points stand for locations, links for circulation access. Whether in a matrix or in a graph the information they represent is the same: concerning the existence of access between locations and the overall structure of relationships of adjacency or inbetweeness of location.

In architectural research, graphs are used principally to represent two kinds of information, namely the adjacent relationship or the accessing relationship between spaces, which are usually called an *adjacency graph* and an *access graph, respectively.* In adjacency graphs, a node stands for a space (e.g., a room), and a connection stands for a partition between two spaces (e.g., a wall)[2]. In access graphs, a node represents a space, and a link represents an access (usually a circulation access) between two spaces (Hillier and Hanson, 1984; Fang, 1993). Access graphs are mostly used in studying the topological organization of a building.

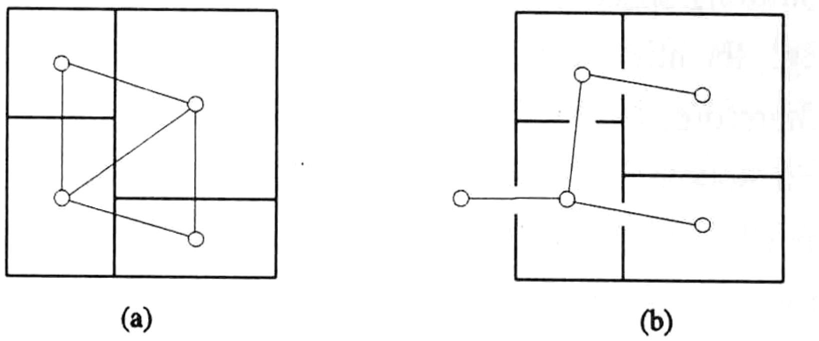


Figure 7.1: Adjacency and Access Graph (Source: Fang, 1993)

Because of the rigorous but simple structure of graphs, they are easily adapted to computation, and so can be used to solve important organizational problems in the built environment linked with topological constraints of space. Zandi-nia (1990) has proposed a system which can automatically generate or evaluate topological organizations according to some constraints. In chapter 4 we have identified that *topological constraints* can lead to potential interaction in a building complex. The way to represent the topological organization of building in terms of access graphs can be consequently used in our system.

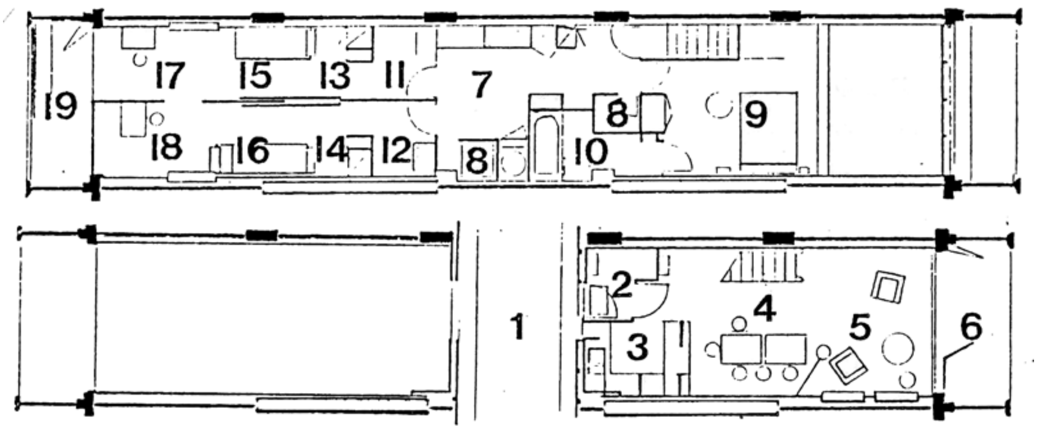
7.2 A typological nested method

The tool under development is aimed at helping the spatial organization of knowledge producing facilities within which clusters of high diversity might be formed. Given the fact that we focus here on the topological aspects, graphs are clearly a good way to

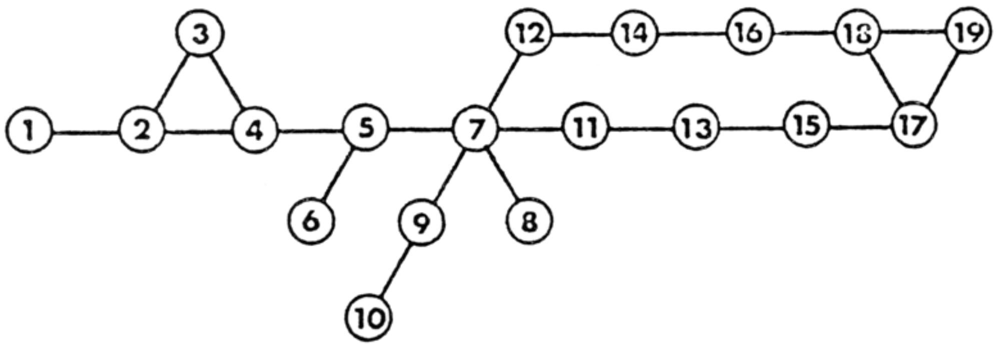
[2] The adjacency graph was first introduced into architecture by Grason (1968) to solve the problems of spatial layout. He exhaustively generates all possible adjacency graphs with the proper number of nodes, considering the topological restrains of the problem, and information on both wall directions and wall lengths was added so as to reach specified solutions.

represent such aspects in a clear manner. Given the fact that we are interested in an applied tool and that the generation, as well as the evaluation of realistic architectural plans can be highly complex, we are interested in ways through which the topological complexity of facilities can be reduced and simplified into easily identifiable patterns. For this purpose the tool draws on work done in this direction by Tzonis and Oorschot (1987). The built environment is treated only as a container of activities, or in other words, a problem in which the only concern is how people and materials can or cannot flow from one place to another.

Here is how the topological organization of a well known architectural building can be represented:



Part of the Unité d' Habitation plan



Circulation access of the plan

Figure 7.2: Transferring Le Corbusier's Unité d'Habitation plan into circulation access (Source: Tzonis and Oorschot, 1987)

To reduce the complexity of the topological organization of projects such as Innovation

Facilities the system proposes the following patterns:

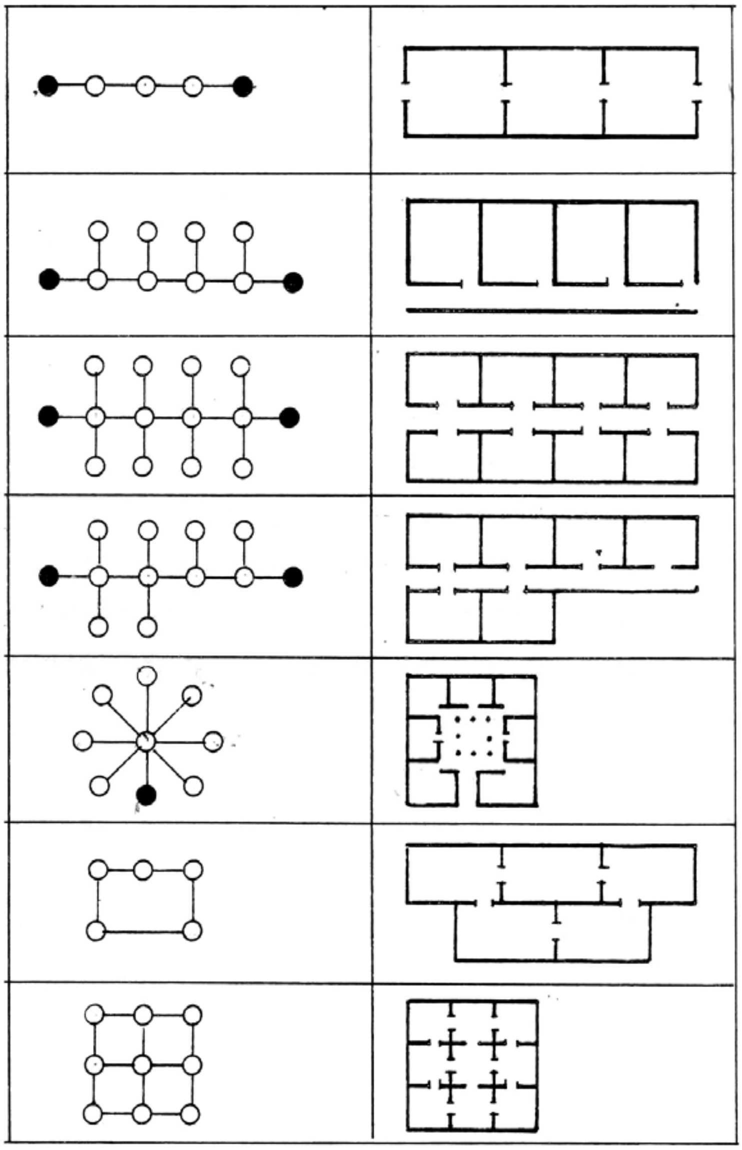


Figure 7.3: Circulation access in different types of plans (Source: Tzonis and Oorschot, 1987)

The spatial information of a building can be classified at different levels of abstraction. Tzonis and Oorschot (1987) identify three levels of abstraction as:

1. Locations, in which some activities, people, or other elements are gathered or placed (Allocation);

2. Topological arrangement, the way locations are connected together and are accessible from each other (Topology);

3. Metrics, the shape and the size of locations (Typology).

Considering that not all complex graphs are decomposable, it is hence not easy to simplify them. Special algorithms are suggested for analyzing such complex graphs. The second important information it gets from Tzonis's system is that: to start reading those basic topological patterns in buildings and to begin to recognize the possibilities inherent in each generic morphological type in relation to their functional performance.

For example, a complex graph can be seen as a combination of simple prototypes. Therefore a complex graph can be represented by simplified graphs with some labels.

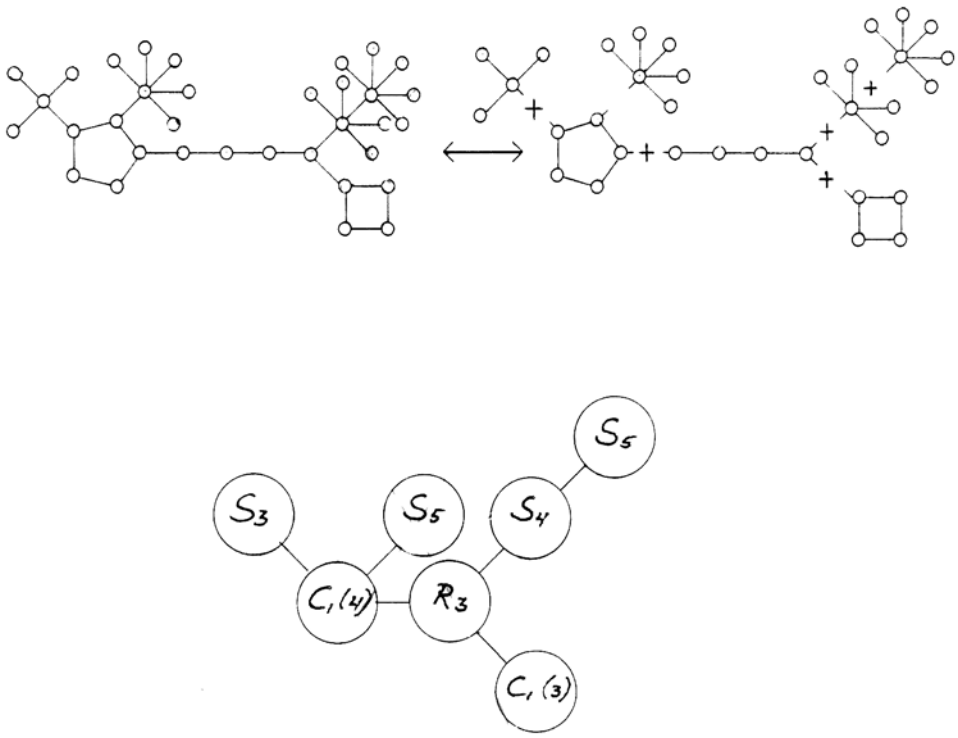


Figure 7.4: Dismantling and representing spatial clusters as 'prototypes' (source: Tzonis & Oorschot, 1987)

Given this system, we can assume that the spatial structure of building complexes can be represented in terms of nodes and links. These nodes are containers of activities which are constrained by spatial organization. A prototype analytical tool system to represent the clustering of locations and flow of activities is necessary, in which the allocation of locations in a given graph of topological constraints needs to be considered.

The representation system created by Tzonis and Oorschot was later developed by Chitchian (1997) into a tree-based structure representation method, which reveals the hierarchical nature of floor plans design explicitly, so that it can be used for the stepwise generation of plans. Chitchian (1997: 7) argued: "*the whole information about a floor plan is not kept together in one place. Rather only the associated information about any cluster, collection of related locations of the plan, is kept or represented together at one level*". Therefore, Chitchian suggested "*Having different levels of information enables us to focus only on the main information at one level while leaving the detailed information to be available at other levels*". Chitchian claimed that: "*Using a tree-based structure for floor plan representation, locations of the plan are grouped recursively in clusters*". Based on this point, locations may be bunched together if they share a common relationship. If a single location and its adjacent locations share some common relationship, then they are assumed to form a single cluster. Even though a single location and its non-adjecent locations share some common relationship, they can still be assumed to form a single cluster. Consequently, in Chitchian's tree-based structure, any node of the tree represents one cluster or one area of the plan, and smaller spaces of the cluster are shown as the child nodes of that node.

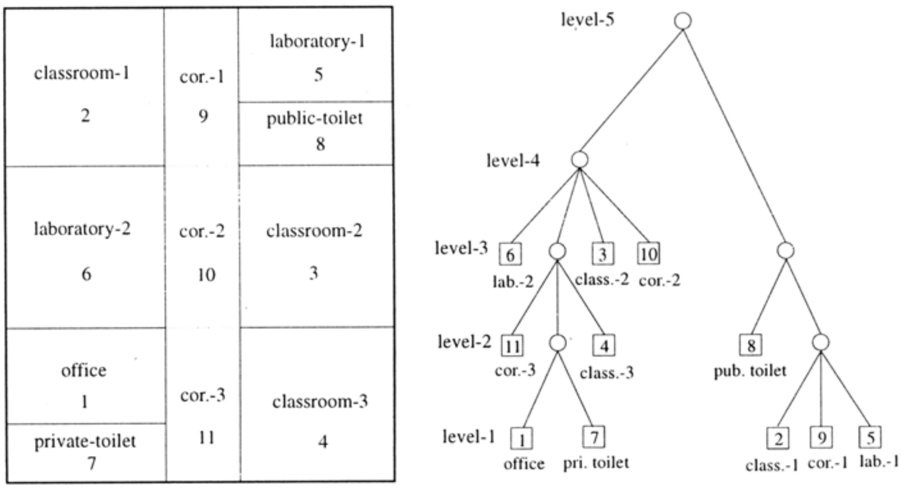


Figure 7.5: Chitchian's Tree Representation model (source: Chitchian's, 1997)

Chitchian's tree representation system suggests that spatial organization should be represented in a tree-like hierarchical structure, in which locations and activities are grouped in *clusters*, so that if a single location and its adjacent locations share some common relationship, then they are assumed to form a single cluster. In our research there are two kinds of clustering: clustering of locations which share similar activities; and clustering of users of these locations.

7.3 Archigraph

7.3.1 What is an Archigraph?

Drawing from current theories of representation of topological spatial relations in buildings, we proceed with accepting the node-link graph convention as a basic component of our tool which we will call ‘Archigraph’ to identify cluster of locations.

The spatial structure of the Archigraph uses the same graph concepts we encountered when discussing the problems of the ‘Sociogram’ in the previous chapter. Locations of activity places are identified as ‘*clusters*’ of locations in the ‘*Archigraph*’; actors interacting are identified as ‘*clusters*’ of users in the ‘*Sociogram*’.

7.3.2 Basic criteria in Archigraph relating to diversity

The Archigraph properties relating to the potential for diversity can accordingly be transferred from Sociogram.

7.3.2.1 Criterion 1 - Connectivity: good or bad for diversity in clusters?

In an Archigraph with high connectivity, it is easy for its users to meet each other. In such an Archigraph, the more connections a node has, the more chance there is for its users to get familiar to each other, and the less diverse they are. Therefore, in an Archigraph, the higher the connectivity is, the lower the diversity of its users will be.

7.3.2.2 Criterion 2 - Reachability: good or bad for diversity in clusters?

In an Archigraph with high reachability, it is easy for users to meet each other. In such an Archigraph, the more reachable a node is, the less the diversity of the cluster that interacting people form.

7.3.2.3 Criterion 3 - Robustness: good or bad for diversity in clusters?

In an Archigraph with high robustness, it is easier to recover the network when it is destroyed or damaged. This high robustness consequently leads to lower diversity on the basis of those connections reconstructed after being damaged. Therefore, in an Archigraph, the higher the robustness, the lower the diversity will be.

7.3.2.4 Criterion 4 - Betweenness: good or bad for diversity in clusters?

A node with high betweenness has great influence over who moves in the network. The more betweness there is in a cluster, the higher the robustness. Therefore, in an Archigraph, the higher the betweenness is, the lower the diversity will be.

7.3.2.5 Criterion 5: Centrality and Periphery (Eccentricity): good or bad for diversity in clusters?

A highly-centralized cluster has a lower Eccentricity. In such a network, powerful central nodes tightly connect most agents who easily become familiar with each other because of the existence of these central actors. The internal diversity thus declines. On the other hand, the peripheral network has a higher Eccentricity, and consequently it has a higher potential for diversity. Therefore, centrality is bad for diversity but the periphery is good for diversity, and the higher the Eccentricity, the better it is for diversity.

7.3.2.6 Criterion 6: Degreeness: good or bad for diversity in clusters?

In an Archigraph with high degreeness, it is easy for users to meet each other. In such a cluster, the higher the degreness a node has, the less possible it is for the users to contact diverse people. Therefore, in an Archigraph, the higher the degreeness is, the lower the diversity will be.

7.3.2.7 Criterion 7 - Density: good or bad for diversity in clusters?

In an Archigraph with high density, it is easy for users to meet each other. The higher the density in an Archigraph, the less possible it is for the users to contact diverse people. Therefore, in an Archigraph, the higher the density, the lower the diversity will be.

7.3.2.8 Criterion 8 - Transitivity: good or bad for diversity in clusters?

In an Archigraph with high transitivity, it is easy for users to meet each other. The higher the transitivity in an Archigraph, the less possible it is for the users to contact diverse people. Therefore, in an Archigraph, the higher the transitivity, the lower the diversity will be.

7.3.2.9 Comparison of these criteria on diversity

After a study of these important criteria in the Archigraph for relating to diversity in a cluster, we can summarize the key points in a table below.

	Connectivity	Reachability	Robustness	Betweenness	Eccentricity	Degreeness	Density	Transitivity
Good for diversity?	No	No	No	No	Yes	No	No	No

Table 7.1: Sum influences of Archigraph criteria to diversity in cluster

7.4 Conclusion

Through the Archigraph representation of a building complex and the above indices, we can identify how a location is topologically connected with the rest of the locations and what its potential for forming a cluster of interaction is. In addition, given the kinds of group that occupy the rest of the locations, we can identify the degree of diversity of that cluster. In the next chapter we apply these ideas and construct the design tool.

CHAPTER 8

THE DESIGN TOOL: 'DNAS'

Construction of the Design tool and Illustration of its Use

In the previous chapters, two models needed for the development of the design tool: the Sociogram and Archigraph have been built. In this chapter these two models will be brought together to construct the design tool, 'DNAS' (**D**iversity **N**etwork **A**nalysis **S**ystem). Concrete examples are brought in to illustrate the various possible applications of the design tool.

8.1 Construction of the design tool

Tools are introduced in the production process to improve efficiency, effectiveness and reliability. In our case the tool is intellectual. It is also intended as the physical tool to improve a specific type of production, the design of sustainable knowledge producing facilities.

8.1.1 Principles and steps in the design of the design tool

There are a few basic principles that are shared by most tool designers. The general design process consists of five basic steps which actually overlap each other (Society of Manufacturing Engineers; 1991):

1. **Identification of problem**: Make statement and analysis of the problem, and identify exactly what is to be done. In chapter 1 we have identified that the problem in current Innovation Facilities is that to ensure the sustainable production of new knowledge, it is necessary to combine advantages from both virtual and physical means in the New Environment. In order to counter

the risk of 'Cyberbalkanization', it is better to enhance potential physical interactions among diverse researchers;

2. **Analysis of requirements**: Analyze the requirements which may help solve the problems, and identify the parameters within which the task must be accomplished. In chapter 4, we have identified some necessary requirements for promoting diversity in clusters, among which topological constraint is identified as a key condition. In chapters 2 and 3 we have also studied how to measure and identify diversity of interacting groups in clusters;

3. **Development of initial ideas**: These ideas should roughly satisfy the aforementioned requirements to solve the aforementioned problems. This step is to formulate the initial design ideas summarized above. To implement those ideas two models have been developed from existing theories: the *Sociogram* and the *Archigraph*;

4. **Development of design alternatives**: These design alternatives are physical and practical means to realize those initial ideas. This step involves determining several methods of performing the task to be done. In developing these initial ideas into design alternatives, the following parameters are suggested: 1) How many agents meet? (the parameter being the number of Persons); 2) How different are they (parameter: disciplines and social distance); 3) How many times they meet (parameter: weighting); 4) What topological spatial conditions (in terms of Allocation and Typology) will increase or decrease the meeting potential (Archigraph Model);

5. **Finalization of design ideas**: Edit these practical alternatives into a knowledge system. This is to select the ones most acceptable and systemize the tool design. We will synthesize relating knowledge systems into a concrete design tool using the criteria, steps and parameters mentioned above. There will be several subsystems in the knowledge system in this design tool: 1) A *Translation System* that can transfer social relationships into a 'Sociogram', and spatial relationships into an 'Archigraph'; 2) An *Estimation System* that can quantify the 'Diversity Index' on the basis of the 'Sociogram' and 'Archigraph'; 3) An *Identification System* that tells which allocations or 'Prototype' will lead to the highest diversity of interacting groups in clusters.

8.1.2 Main Framework of the design tool ‘DNAS’

Based on different beliefs, designers might have varying rules to guide their design thinking and acting. However, the decisions they make are basically based on certain universal structures of thinking. Tzonis, Berwick and Freeman (1978) represented a minimal structure of thinking with the universal concepts of norm, fact, and directive, in the Kernel of Conceptual System. This particular scheme described an interlocking relationship of norm, fact, and directive that constrains design thinking. Tzonis and Oorschot (1987) believed that the basic design thinking should consist of two processes: 1) The process of generating a plan from a program, and 2) The process of justifying a plan in relation to a program. These processes point out two main functions of our design tool: the tool as *design evaluator*; and the tool as *design generator*.

As a result, there are also two processes in the proposed design tool ‘DNAS’ (**D**iversity **N**etwork **A**nalysis **S**ystem). The framework of the design tool ‘DNAS’ can be represented in two kinds of graphical chain as shown below. The function of DNAS I is to identify the best design solution with the highest diversity performance from candidate solutions. However in DNAS II the aim is to generate the best design solution with the highest diversity performance from all possible syntheses of different forms of schemes and allocations of locational usage in these schemes.

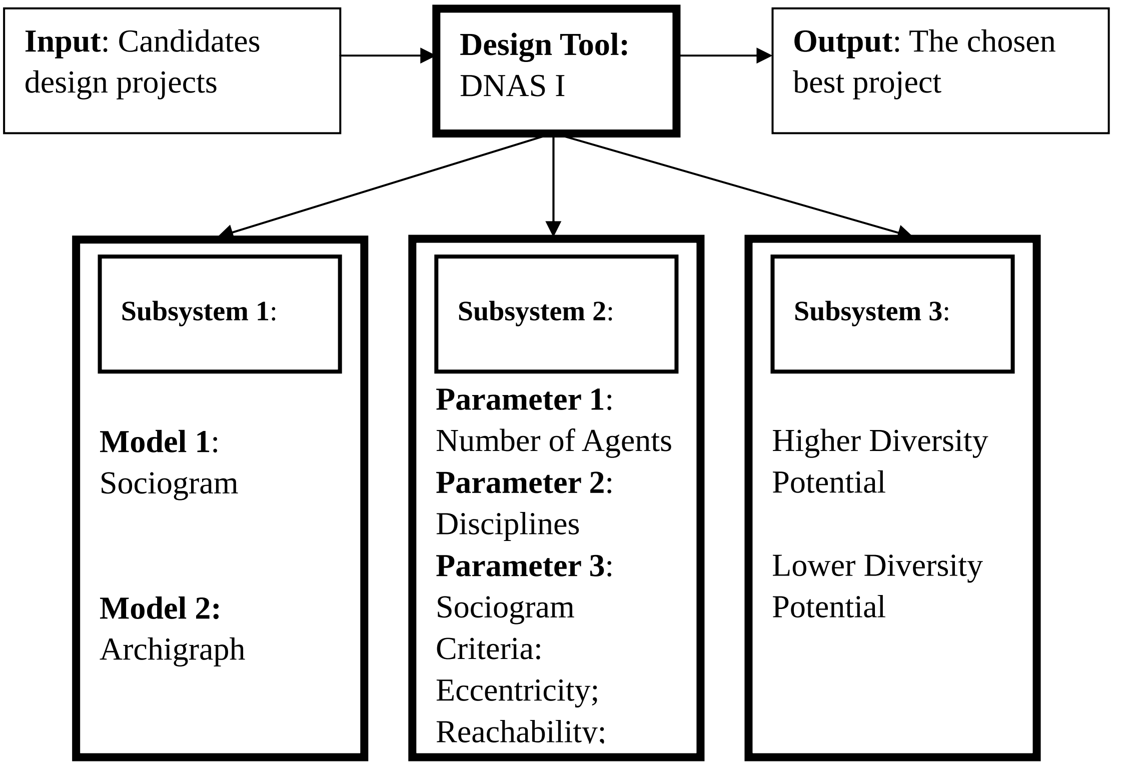


Figure 8.1: DNA-I: The framework of the design tool for design evaluation.

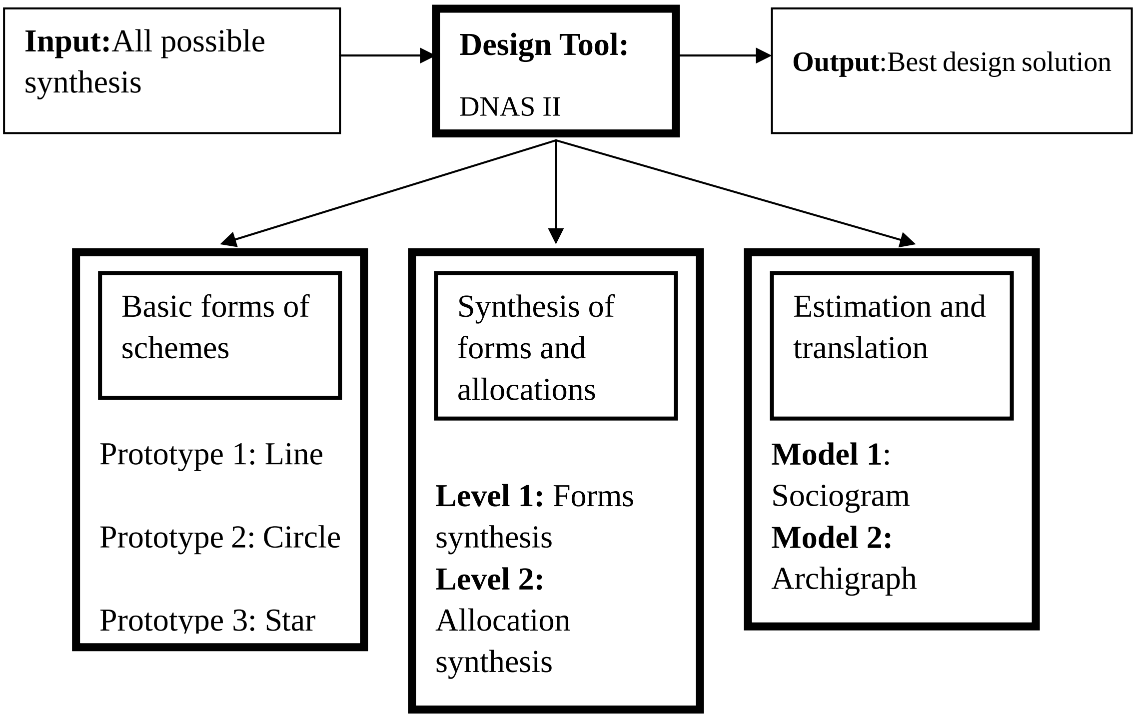


Figure 8.2: DNA-II: The framework of the design tool for design generation.

8.2 Background knowledge in the tool ‘DNAS’

From the previous requirements to construct a tool, we shall assemble the relevant existing knowledge and synthesize it into a systematic framework as a general design tool. We will arrange the concepts into basic knowledge statements, and then synthesize them into a systemic, knowledge-based tool.

8.2.1 Statements of basic knowledge in the tool

Statement 1. The MOP chain: Morphology-Operation-Performance

This Kernel of Conceptual System can be used alongside a framework for the representation of architectural knowledge, which consists of interlocking relationships of Morphology, Operation, and Performance (MOP) in certain contexts. Tzonis (1992: 147) first demonstrated this MOP framework of representing knowledge in studying a case example of Unité d’Habitation, where Le Corbusier mapped by analogy the relationship and structure of various precedent entities and properties of ‘hut’, ‘ship’, and ‘bottle-rack’ into the new apartment complex design with MOP. Later MOP has been used to investigate architectural design thinking in different contexts and situations (Zandi-nia 1992; Fang 1993; Li 1993; Jeng 1995; Zarzar 2003). According to Tzonis: *Morphology* refers to the formal aspects of a building or urban design; *Operation* refers to the processes of use of a building, and the role of form in these processes; and *Performance* refers to the conditions a prospective building is intended to bring about, or the degree to which a scheme of a building brings these conditions about. In our case, the interaction of diverse researchers is the performance to pursue; we thus study morphological characteristics of Innovation Facilities under certain operations with the aim of enhancing the interaction of diverse researchers.

As concluded by Hillier (1984), built form and spatial organization have subsequent social consequences; misunderstanding the nature of the relation between spatial organization and social life is the chief obstacle to better design. MOP seems to provide a better understanding between spatial organization (in terms of spatial morphology) and the related social life it causes. The morphological characteristics of a building can constrain potential flow within the building. As a result, the flow can potentially determine whether users in building will meet each other or not, where they will meet, and under what conditions. Consequently, the interaction property finally causes information exchange and performance in terms of social quality. Tzonis (1987) described this consequence as a chain as follows:

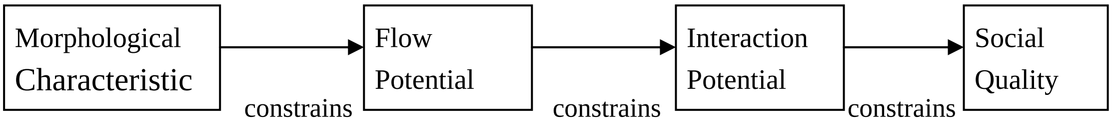


Figure 8.3: Social consequence of morphology (source: Tzonis and Oorschot, 1987, p132)

To forecast the performance of a building, such as whether it is ‘good or bad for security’, ‘good or bad for privacy’, ‘good or bad for community’, or ‘good or bad for diversity’, the crucial point is to understand the chain of Form-Operation-Performance. Here social quality is further defined in detailed categories with different interests or emphasis. Morphological characteristics of buildings are further identified as the ‘Form’ of buildings. Between these two important points lies Operation. Since every form has its inherent characteristics of topology because of diverse types of morphologies, if some operations are performed, then their related performance can be estimated (whether it is good, and what it is good for). This chain may be represented as:

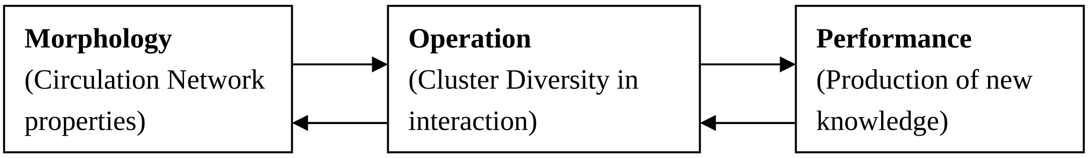


Figure 8.4: Relationship between Form, Operation and Performance (source: Lecture by Tzonis)

In our problem solving process, we focus on which kind of form will cause higher or lower diversity performance. The operation is to observe: If researchers were deliberately allocated into those various locations, would these arrangements make the interaction of diverse researchers more or less possible. As stated in the first point of view, the morphological characteristics of a building potentially decide whether or not two users can meet each other.

Statement 3. The measurement of interaction of diverse researchers (See Chapter 2)

As ‘diversity of interacting of groups in clusters’ is taken as a basic necessary condition for promoting sustainable innovation, we look at the concept of diversity which has been discussed in chapters 2 and 3. Some remarks can be concluded as follows:

1. Species richness, and evenness are two basic measurements of individual and group diversity;
2. In Innovation Facilities, to measure diversity, two distances need to be measured: disciplines distance and social distance;
3. The New-networked structure requires diverse people work in a cluster to maximize creativity;
4. A cluster is the container in which diversity occurs and evolves;
5. To maintain long-term creativity in a cluster, we need a dynamic balance between Heterogeneity and Homogeneity;
6. A cluster can bridge both external diversity and internal diversity.

Therefore, the *Diversity Index* in a cluster can be estimated by multiplying the number of valid members of the cluster by the maximal difference among members in the cluster. The species richness will be estimated as the difference of disciplines and difference of social criteria; the evenness will be the numbers of the researchers coming from the same disciplines. The diversity index in a cluster can hence be estimated by an equation:

$$\mathbf{D = Nc \times (Dd+Ds+Do)}$$

Equation 8.1: Estimation of General Diversity Index

in which D represents the diversity index; Nc represents the valid number of members inside the cluster of location; Dd represents the maximal difference between disciplines inside a cluster (identified as ‘*the third difference*’ in chapter 2); Ds represents the maximal difference between the Sociogram criteria in a cluster, which is identified as the first and the second dimension in chapter 2; Do represents the maximum difference between other criteria such as gender difference, age difference, race difference, and so on as mentioned in chapter 2, which are called the primary (or first) and secondary (second) difference. However, the estimation equation presented in this design tool is just to provide a simplified procedure reflecting the potential performance of diversity in clusters. To have a precise estimation it requires more mathematical techniques.

Because here we are mainly concentrating on maximal differences between disciplines, and between Sociogram criteria, we temporally ignore Do. The equation is this simplified to:

D = Nc × (Dd+Ds) **Equation 8.2:** Simplified Estimation of General Diversity Index

Later in this chapter we consider how to identify a cluster before we can measure its diversity.

Statement 4. The identification of a cluster (See Chapter 3)

Cluster theory has been introduced in chapter 3. Clusters work in three broad ways which rely heavily on *face-to-face physical interaction* and *personal relationship*. Therefore, to achieve new knowledge production in clusters, we have to represent personal relationships in a cluster in terms of Model I '*Sociogram*', and organize face-to-face physical interaction constrained by Model II 'Archigraph'. At the end of chapter 3, it was concluded that two criteria could determine the existence of a cluster, or what we may term 'clustership': similar interest or characteristics, and close distance.

Clustering Agents in a Sociogram

Firstly, we identify clusters in a Sociogram. We take one node from the Sociogram and examine around him (her) how many agents are (informationally) connected to him (her) within only one span. All those linked agents and the central agent are considered as members of a 'cluster' in which academic information flows, being passed through trusted personal ties. In chapter 3 we have explained why we only consider agents with less than 2 connections in a social cluster as a valid distance to judge clustership (because trustable close personal ties can not be extended over too long social distance);

Clustering Locations in an Archigraph

Secondly, we identify clusters in an Archigraph. One node is taken from the Archigraph to identify how many locations around it are connected to it within only one or two spans. All these locations and the selected node are considered as members of a 'cluster' of locations. We have explained that the closer the locations, the easier it is to have clustering activities in them because of the time-distance constraints.

Statement 5. Sociogram and Archigraph (See Chapters 6 and 7)

We have introduced the methods and concepts of the Sociogram in Chapter 6 and the Archigraph in chapter 7. Here we will just briefly review some of their key points. The mechanism proposed by Tzonis provides a channel to evaluate social consequences of architecture with inherent morphological characteristics. However, it is not enough to precisely observe the social consequence of inherent architectural morphology. We need exact models to represent architectural topology and social topology. The network is an ideal form to be employed for this. Whether by Euclidean or non-Euclidean measurements, any complex things sharing similar activities can be represented in terms of a network which has only two kinds of elements: nodes and linkages between these nodes. Therefore buildings can be represented in terms of a network model, and social actors using these buildings by another network model.

Model 1: Representation of Social Network--- the **Sociogram** in Innovation Facilities (See Chapter 6) is defined as: a charting of the inter-relationships of information flow within an Innovation Facility. Its purpose is to discover academic group structure: i.e., the basic "network" of information flow patterns and sub-group organization.

Model 2: Representation of Architectural Network--- the Archigraph (See Chapter 7) is drawn from current theories of representation of topological spatial relations in buildings, and the node-link graph convention is accepted as a basic component of our tool which we call the 'Archigraph' to identify clusters of locations. The spatial structure of the Archigraph uses the same graph concepts we have encountered discussing the problems of the 'Sociogram'.

Locations of activities places are identified as '*clusters*' of space in the '*Archigraph*'; actors interacting are identified as '*clusters*' of users in the '*Sociogram*'.

Statement 6. Unification of different Criteria for the Sociogram: (See Chapter 6)

We have suggested that the species richness may be estimated as the difference of disciplines and difference of social criteria. To measure social difference those criteria developed in chapter 6 can be used. These include: Connectivity; Reachability; Robustness; Betweenness; Centrality and Periphery (Eccentricity); Degreeness; Density; and Transitivity. It is concluded that all these criteria (except Eccentricity) have similar negative impact to diversity potential. We use ‘connectivity’ as a ‘*representative criterion*’ to represent the others. We measure the maximal difference between the values of ‘connectivity’ of all members in a cluster as the representative difference of Sociogram of the cluster. We measure the maximal difference between the values of ‘eccentricity’ of all members in a cluster as another representative difference since eccentricity has positive impact to diversity potential. The sum of these two kinds of impacts (negative and positive) can roughly reflect the cluster’s performance of diversity potential, although a more advanced technique is expected. The summed difference (Ds) is the sum of the maximum difference between eccentricity among all agents in the cluster (De), and the maximum difference in the representative criterion (to represent other criteria) among all agents in the cluster (Dr). This is described by another equation: Ds=De+Dr.

Statement 7. A Design Tool

The morphological characteristics of Architecture have been represented in ‘Archigraphs’; and the social relationships between users of the Archigraphs in ‘Sociograms’. There are laws determining the relationship between these two kinds of networks, which potentially determine the interaction profiles and the social performance. Considering the complex and richness of ‘social performance’, the MOP chain is actually represented by a more complex system as follows:

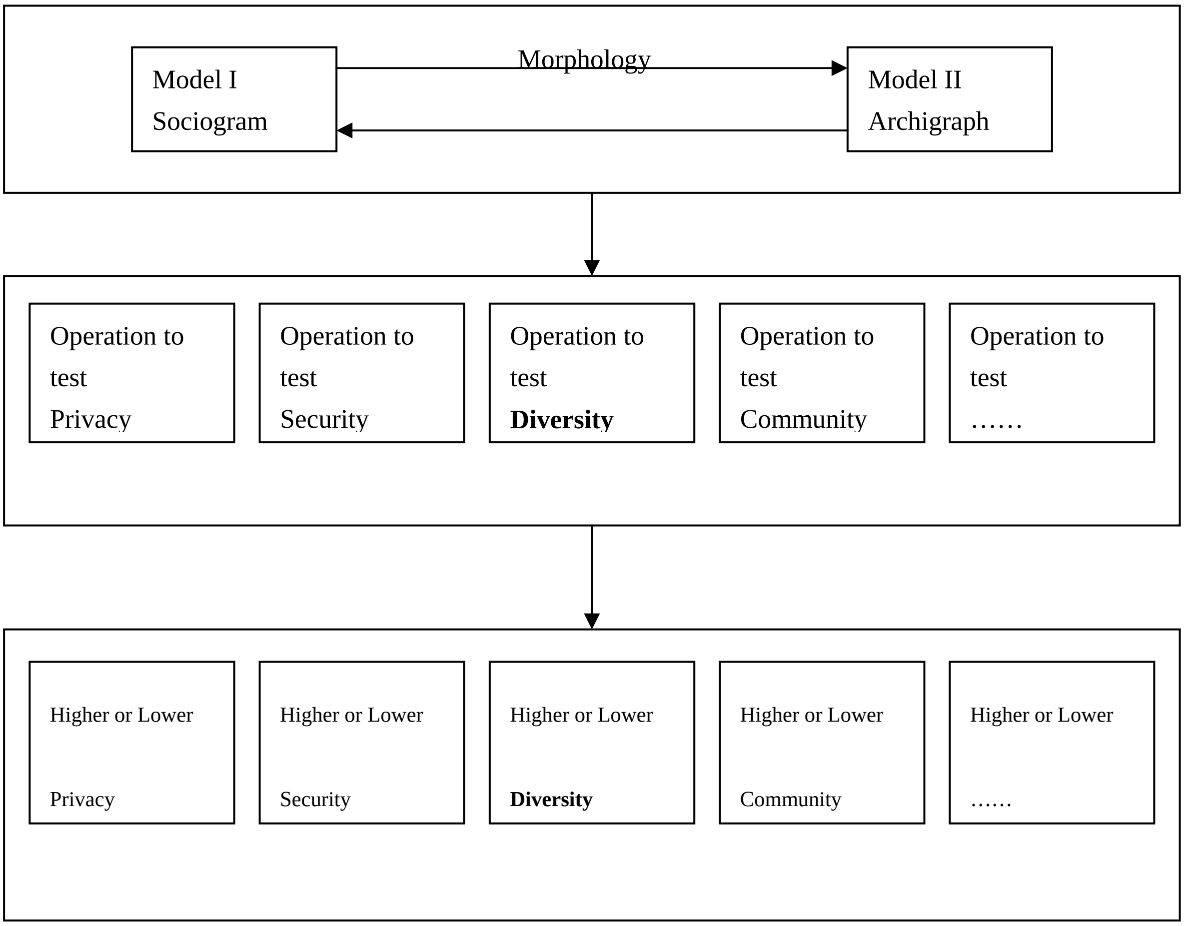


Figure 8.5: An extended system of Form-Operation-Performance for developing the design tool

Note: Due to possible internal conflicts in performances, operation, and forms, a Multiple-criteria method is suggested for extension of the tool

A design tool is a means to visualize the interaction between these two kinds of networks to understand various potential social consequences. One of these is the performance of diversity. The kernel of the tool is roughly described by the following procedure: representing the buildings in an Archigraph, and social relationship in a Sociogram; allocating users in locations according to design solutions; identifying clusters of locations and users; matching the Sociogram and Archigrah, deleting invalid connections in clusters of users in locations, according to Sociogram constraints; estimating the *Diversity Index* by multiplying the number of valid members of the cluster with the maximum difference between members of the cluster; comparing the summed diversity index to decide which solution has higher diversity potential.

8.2.2 Steps to use the tool

We have mentioned that the design tool can be used to measure the diversity index for three purposes: to evaluate the best design solution; to generate the best allocation for fixed kind of forms in designs; to generate the best design with the best allocation and the best typologies. Here, the concrete steps to develop the tool will be explained.

To *evaluate* candidate solutions of different schemes to determine the one with the highest potential for interaction of diverse researchers from, we suggest:

1. **Translating** building plans into the form of an ‘Archigraph’, and interactions between agents into the form of a ‘Sociogram’;

2. **Clustering** to identify clusters of locations, and to identify clusters of users in these clusters of locations;

3. **Tabulating** to identify and rank the extent of differences, considering disciplinary distance and organizational distance;

4. **Estimating** the potential of interaction of diverse researchers using the Equation: D = Nc × (Dd+Ds);

5. **Identifying** the design solution with the highest potential for interaction of diverse researchers from the list of candidate schemes.

To *evaluate* different candidate allocations within a given form of scheme to determine the one with the highest potential for the interaction of diverse researchers, we suggest:

1. **Translating** building plans into an ‘Archigraph’ representation, and interactions between agents into a ‘Sociogram’ representation;

2. **Clustering** to identify clusters of locations, and to identify clusters of users in these clusters of locations;

3. **Allocating** a ‘central nodes’ and ‘peripheral nodes’ of the Sociogram to correspond, first to the central and peripheral nodes respectively of the Archigraph, and second in the opposite sense, that is the central nodes of the Sociogram to the peripheral nodes of the Archigraph. (Here, we introduce a heuristic mechanism to reduce endless searching) First allocate a ‘central node’ (low eccentricity) in the Sociogram to the location of the ‘central node’ in the Archigraph (situation 1); Secondly, allocate a ‘central node’ in the Sociogram to the location of the ‘peripheral node’ (high eccentricity) in the Archigraph (situation 2). Allocating a ‘peripheral node’ in the Sociogram to the location of the ‘peripheral node’ in the Archigraph is the same as situation 1, and allocating ‘peripheral nodes’ in Sociogram to the location of the ‘central nodes’ in Archigraph is the same as situation 2, and so these are not considered as additional variants.

4. **Estimating** the potential for interaction of diverse researchers by the same equation: D = Nc × (Dd+Ds);

5. **Identifying** the allocation with the highest potential for the interaction of diverse researchers from the list of candidate allocations.

To *generate* the highest diversity index design from endless possible combinations of different allocations and different forms of schemes of plans, we suggest:

1. **Identifying** basic types of building schemes such as ‘linear’, ‘circular’, and ‘Star’, according to their topological relationships;

2. **Generating** different design solutions by combining basic types of architectural schemes;

3. **Allocating** different activities and groups of users to the available locations in the topological scheme generated by step 2;

4. **Estimating** the potential for interaction of diverse researchers by the equation: D = Nc × (Dd+Ds), to estimate the total index for all generated combinations of different allocations and different forms of schemes of plans;

5. **Identifying** the best combinational solution, with the highest potential for interaction of diverse researchers, from a list of combinations of different generated types of schemes and different locational allocations within these schemes;

6. **Translating** this best combinational scheme into a real architectural plan (This step will be omitted in the research).

In the following sections we will use concrete examples to illustrate the different applications of the design tool 'DNAS'

8.3 Using 'DNAS' for design evaluation

In this section the function of the design tool as design evaluator will be exemplified in two examples varying from choosing the best form of schemes in plan, and the best allocation of usages of location in the fixed form of plan.

8.3.1 Example I: Which topology has the highest diversity performance: Line, Grid, Star, or Circle?

I. What is the problem?

A famous university asked four design offices to propose plans for its new campus. They sent four completely different proposed planning solutions to the President of the university. The President of the University had to choose one from them, and wished to know the one with the highest diversity performance, to encourage sustainable innovation in the campus in the future. Because he is a layman of architecture and urban design, he decided to first consult DKS, a well-known research center in this domain. He asked DKS to write a report to evaluate potential diversity performance of all these four design solutions so that he could make a final selection from these candidate solutions.

The question to be solved by the design tool is: which solution will potentially result in the highest diversity performance in the campus? Following the steps mentioned in the previous section, we will illustrate how the design tool can identify an ideal solution from all candidate projects.

II. Solving the problem using the design tool

Step 1. Translating

These four design solutions can be simplified and represented by four Archigraphs, as shown below: (From top to bottom: Solution I; Solution II; Solution III; Solution IV). In these Archigraphs extracted from those design proposals, most details are ignored, so that only the topological location of each faculty is represented as a node, and the main topological paths between them are represented as links between the nodes. It is mainly in these locations that encounters will occur that support the production of innovation.

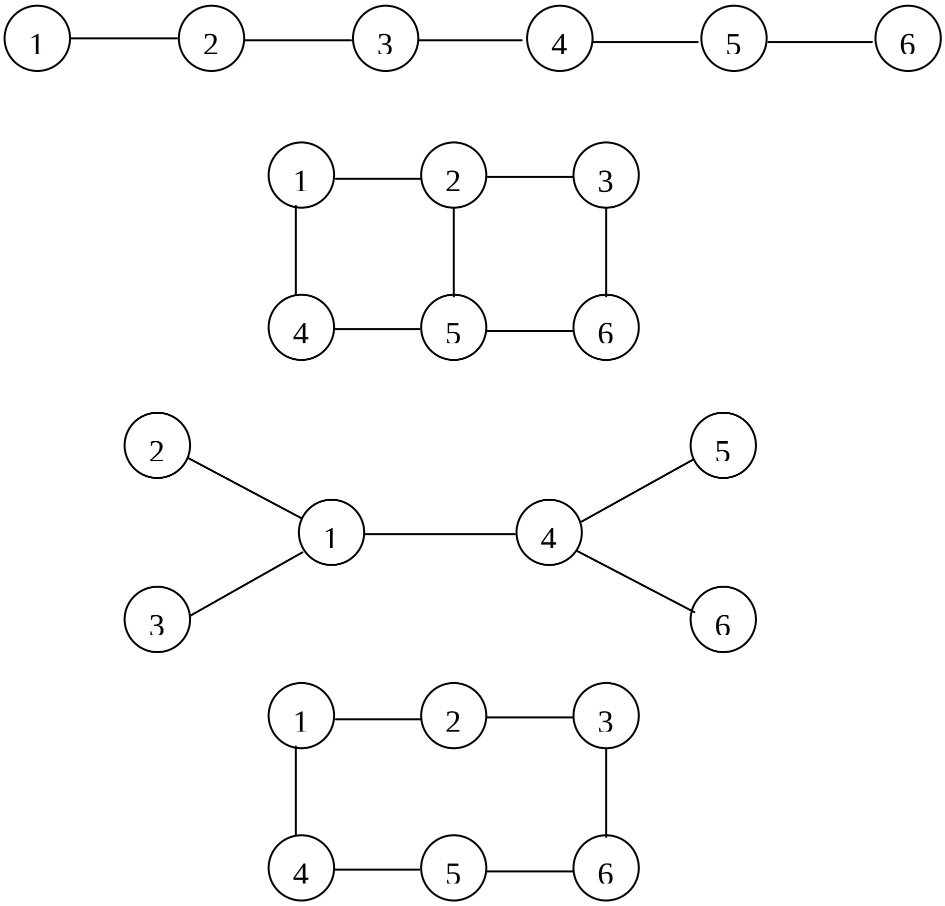


Figure 8.6: Archigraphs in example I: From above to bottom: Solution I; II; III; IV.

Location 1: Faculty of Mathematics; Location 2: Faculty of Physics; Location 3: Faculty of Electrical Engineering; Location 4: Faculty of Economics; Location 5: Faculty of Architecture; Location 6: Faculty of Literature.

To draw a ‘Sociogram’ indicating information flow between researchers in these faculties, the first step is to carry out an investigation by sending questionnaires to researchers in every faculty. If the majority of researchers in one faculty often exchange information with researchers in another faculty, then it shows that an information flow connects these two faculties. In the Sociogram, these two faculties can be connected. It is possible that key researchers in one faculty have significant information exchange with only one other faculty. It is also possible that the key researchers in one faculty have information connections with several other faculties. Therefore in the Sociogram every node represents the group of researchers in one faculty, and every link represents their main information links groups of researchers in other faculties. The Sociogram indicating the information flow in the campus is represented in the graph below, which reveals that nodes a (Faculty of Mathematics) and b (Faculty of Economics) seem to be hubs of information flow.

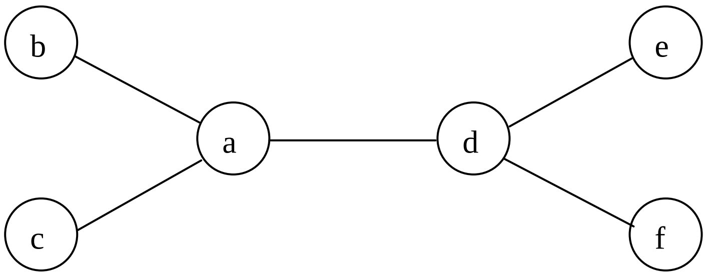


Figure 8.7: Sociogram of researchers in examples

Nodes represent groups of researchers in different faculties as follows: Node a: Faculty of Mathematics; Node b: Faculty of Physics; Node c: Faculty of Electrical Engineering; Node d: in the Faculty of Economics; Node e: the Faculty of Architecture; Node f: the Faculty of Literature.

Step 2. Clustering

In the Sociogram, taking one node as the center of a cluster, only those nodes within one connection distance with it can be seen as members of this cluster. Accordingly the cluster can be labeled in terms of the name of this central node. The identification of all clusters in the Sociogram is presented in the table below:

Name of Cluster	Cluster A	Cluster B	Cluster C	Cluster D	Cluster E	Cluster F
Center	a	b	c	d	e	f
Members	a, b, c, d	a, b	a, c	a , d, e, f	d, e	d , f

Table 8.1: Clusters in the Sociogram.

Similarly, in the Archigraphs, taking one node as the center of a cluster, only those nodes within one connection distance of it can be seen as members of this cluster. The clusters can again be labeled in terms of the name of this central node. The identification of all clusters in the Archigraphs is presented in the table below:

Name of Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Center	1	2	3	4	5	6
Solution 1	1, 2	1, 2, 3	2, 3, 4	3, 4, 5	4, 5, 6	5, 6
Solution 2	1, 2, 4	1, 2, 3, 5	2, 3, 6	1, 4, 5	2, 4, 5, 6	3, 5, 6
Solution 3	1, 2, 3, 4	1, 2	1, 3	1, 4, 5, 6	4, 5	4, 6
Solution 4	1, 2, 4	1, 2, 3	2, 3, 6	1, 4, 5	4, 5, 6	3, 5, 6

Table 8.2: Table of clusters of locations for each solution.

Step 3. Tabulating

The main differences between disciplines and between social criteria can be listed in the tables below. In the table, the greater the difference between the codes of the disciplines, the sharper the difference between disciplines. For example, Dd between Group a and Group d can be counted as 4 -1=3. Here, this table just provides a rough reflection of difference between disciplines. However, the precise difference between disciplines could be more complex and needs be estimated by more advanced technique.

Researcher groups in Sociogram	Background of group	Discipline Codes
Group a	Mathematics	1
Group b	Physics	2
Group c	Engineering	3
Group d	Economics	4
Group e	Architecture	5
Group f	Literature	6

Table 8.3: Table of difference between disciplines (the more difference between the codes of the disciplines, the sharper the different between disciplines).

	Group a	Group b	Group c	Group d	Group e	Group f
Eccentricity	2	3	3	2	3	3
Central node	Yes			Yes		
Peripheral node		Yes	Yes		Yes	Yes
Connectivity	3	1	1	3	1	1

Table 8.4: Table of differences in Sociogram

Step 4. Estimating - the Diversity Index

Starting from those background knowledge reviewed in this chapter, the clusters of locations and researchers, and the valid cluster properties, Nc, Dd, Ds, and D are estimated and tabulated for each of the design options. The valid users of a location are hence constrained by both the Sociogram and the Archigram. Only users in the same cluster of locations in the Archigraph, and in the same cluster of researchers in the Sociogram can be counted as valid members in the potential social interaction. In this way, the Archigraph and Sociogram are bridged and mapped. Then these valid members can be identified as the number of a cluster when we calculate the Diversity Index.

In the tables which follow, Nc means the number of valid members allocated in a cluster of locations in the Archigraph. These users are at the same time members of the same cluster in the Sociogram, since otherwise they cannot be identified as valid users in this cluster of locations. The differences between the different disciplines are listed in another column in the table. Dd means the maximum difference between disciplines of researchers in a cluster in the Sociogram. Ds is the summed maximum difference between Sociogram criteria among members in a cluster of researchers in the Sociogram. Ds can be estimated from the equation: Ds=De+Dr, in which De is the maximum difference between users in terms of differences of Eccentricity, and Dr is the maximum differences of Sociogram norms between users in terms of the maximum differences of Connectivity. As mentioned before, one key criterion, ‘Connectivity’, is selected as the representative criterion to represent the other criteria’s influences on diversity, on the basis of their similar influences diversity (see the end of chapter 6). Therefore, in a cluster in the Sociogram, the node with the biggest Connectivity and the one with the least Connectivity are chosen, the difference between them are counted as Dr. For example, De between Group a and Group e is 3-2=1; Dr between Group a and Group e is 3-1=2, hence Ds between Group a and Group e is 1+2=3. D is the general Diversity index between valid members of a cluster in the Sociogram. The Diversity Index, D, can now be estimated from the equation: D = Nc × (Dd+Ds).

To simplify the problem, we just identify clusters by measuring only one span of connection. For instance: in figure 8.7, a, b, c, and d are connected with each other within one span in a cluster around a, there are hence 4 members in this cluster. The maximum discipline distance (Dd) between members inside this cluster is the distance between a and d, and so it is 3. The maximum Sociogram difference (Ds) is estimated by summing up the maximum differences between Eccentricities, and between Connectivites. It is (3-2)+(3-1)=3. Therefore: the general diversity index of this cluster can be estimated as: **D = Nc × (Dd+Ds)=4× (3+3)=**24.

Although the diversity index can be estimated from **D = Nc × (Dd+Ds)**, as mentioned, Nc has to be rechecked from the Sociogram, because if in the Sociogram two agents do not exchange information, then there will be no trusted interaction and a very lower possibility of information exchange, even if they are arranged in the same cluster of locations. Therefore if the members in the same location-cluster do not have a one-connection distance in the Sociogram, then their connection in the Archigraph cannot be counted as a valid connection.

Consequently, for all four alternative solutions, the parameters and results for estimating their Diversity Indexes can be listed in 4 tables.

Solution I	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	4	1+2	0
Cluster 4	3, 4, 5	c, d, e	d, e	2	4	1+2	14
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	5, 6	e, f		0	3	0+0	0

Table 8.5: Parameters and results for estimating diversity index for solution 1 in example I.

Total diversity index for the solution I is: 8+15+0+14+15+0=52

Here we assume that the total diversity index can be obtained as the sum of all clusters' partial indexes. However, this method of estimation is just to provide a brief procedure reflecting the potential performance of diversity in clusters. To have a precise estimation requires more mathematical techniques.

Solution II	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 4	a, b, d	a, b, d	3	3	1+2	18
Cluster 2	1, 2, 3, 5	a, b, c, e	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 6	b, c, f		0	4	1+2	0
Cluster 4	1, 4, 5	a, d, e	a, d, e	3	4	1+2	21
Cluster 5	2, 4, 5, 6	b, d, e, f	d, e, f	3	2	1+2	15
Cluster 6	6, 5, 3	e, f, c		0	3	0+0	0

Table 8.6: Parameters and results for estimating diversity index for solution I1 in example I.

Total diversity index for the solution II is: 18+15+0+21+15+0=69

Solution III	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 3, 4	a, b, c, d	a, b, c, d	4	3	1+2	24
Cluster 2	1, 2	a, b	a, b	2	1	1+2	8
Cluster 3	1, 3	a, c	a, c	2	2	1+2	10
Cluster 4	1, 4, 5, 6	a, d, e, f	a, d, e, f	4	5	1+2	32
Cluster 5	4, 5	d, e	d, e	2	1	1+2	8
Cluster 6	4, 6	d, f	d, f	2	2	1+2	10

Table 8.7: Parameters and results for estimating diversity index for solution II1 in example I.

Total diversity index for the solution III is: 24+8+10+32+8+10=92

Solution IV	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 4	a, b, d	a, b, d	3	3	1+2	18
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 6	b, c, f		0	1	0+0	0
Cluster 4	1, 4, 5	a, d, e	a, d, e	3	4	1+2	21
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	5, 6, 3	c, e, f	e, f	0	1	0+0	0

Table 8.8: Parameters and results for estimating diversity index for solution 1V in example I.

Total diversity index for the solution IV is: 18+15+0+21+15+0=69

Step 5. Identifying

According to the results estimated by the design tool, the diversity index of Solution I is 52; of Solution II is 69; of Solution III is 92; of Solution IV is 69, and so solution III has the highest potential for interaction between diverse researchers. The suggestion to the President of the university is that: to have the highest potential of diversitified interactions in the campus in the future, solution III should chosen.

	Solution I	**Solution II**	**Solution III**	**Solution IV**
Total Diversity Index	52	69	92	69

Table 8.9: Comparison of diversity indexes for all solutions in example I.

In this example, actually 4 kinds of prototypes has been used: linear, grid;, star, and ring. This example demonstrates that different forms of the architectural plans have different performances even with the same Sociogram. It seems that when the

Archigram is coincident with the Sociogram (see solution III), the potential for performance is higher than in the other situations.

The President’s inquiry triggered another interesting question. This example illustrates the using of the tool to identify the best design solution for the highest diversified interaction potential, but can the design tool help in deciding the best allocation in a fixed form of plan, because, even with the same Archigraph, if the allocation of users’ locations is changed, the consequent diversity indexes will also change. Therefore a further discussion is suggested to consider different allocations in the same design solution. This will be explained in the next example.

8.3.2 Example II: Which allocation will cause higher diversity: central to central or central to peripheral?

I. What is the problem?

In the previous example the President of the university was satisfied with the evaluation process using the design tool. However he asked another question: Given a fixed typology (for example, the linear typology or the grid), what kind of allocation will cause the highest potential of interaction between diverse researchers? To simplify the question, we selects only the linear and the grid forms to understand how different allocations will influence the diversity performance. Certainly, we could exhaustively list all possible allocations of the locations of the different faculties in the design solutions. However, we will employ a heuristic searching to shorten the path to the solution.

The problems we will investigate are as follows. How can the different allocations within the same typology potentially determine the interaction among diverse researchers? Will central or peripheral nature of locations influence the diversity potential? More precisely, when we allocate a central agent in a Sociogram, to a central location in the Archigraph, will this cause a higher (or lower) diversity potential that if we allocate it to a peripheral location?

II. Solving the problem using the design tool

Step 1. Translating

This has been done in the previous example (see step 1 of example 1)

Step 2. Clustering

This has been done in the previous example (see step 2 of example 1)

Step 3. Allocating center to center or center to periphery

For each of the two solutions (linear and grid) we consider two possible allocation strategies. The first is to allocate central nodes in the Sociogram to central nodes in the Archigraph, and the second it to allocate central Sociogram nodes to peripheral Archigraph nodes. We thus consider two allocations for each of two of the proposed solutions.

The solution designed by the first office may be represented as:

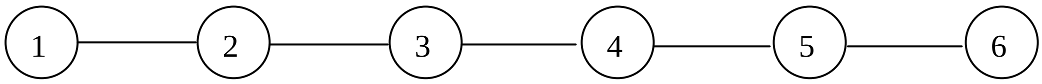


Figure 8.8: Archigraph of Solution I in example II.

By measuring and comparing eccentricity, these 'central nodes' and 'peripheral nodes' can be identified.

Node	1	2	3	4	5	6
Eccentricity	5	4	3	3	4	5
Central Node?			Yes	Yes		
Peripheral Node?	Yes					Yes

Table 8.10: Identifying central and peripheral nodes in Archigraph of Solution I in example II.

The solution designed by the second office is represented as:

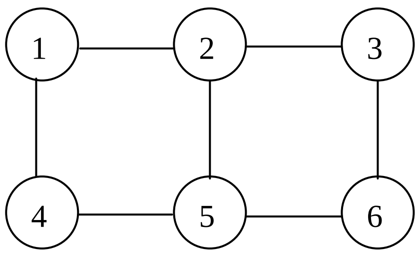


Figure 8.9: Archigraph of Solution II in example II.

By measuring and comparing eccentricity, those 'central nodes' and 'peripheral nodes' can be identified.

Node	1	2	3	4	5	6
Eccentricity	3	2	3	3	2	3
Central Node?		Yes			Yes	
Peripheral Node?	Yes		Yes	Yes		Yes

Table 8.11: Identifying central and peripheral nodes in Archigraph of Solution II in example II.

Similarly, in the Sociogram the central or peripheral nodes can be identified. This has been done in the previous example (see table 8.4 in step 3 of example 1).

Mapping between Sociogram and Archigraph

Allocation 1: In solution 1, we allocate the ‘central node’ of the Sociogram to the location of the ‘central node’ of the Archigraph. That means allocating group a to location C; d to location D; b to A; c to B; e to E; and f to F. If we replace the code of the location with the code of the related faculty, the allocation to the Archigraph is as represented below:

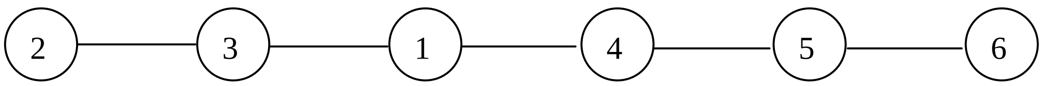


Figure 8.10: Allocation I for Archigraph in example II.

Allocation 2: In solution 1, we allocate the ‘central node’ of the Sociogram to the location of the ‘peripheral node’ of the Archigraph. That means allocating: a to A; d to F; b to B; c to C; e to D; and f to E. If we replace the code of the location with the code of the related faculties, the allocation to the Archigraph is as represented below:

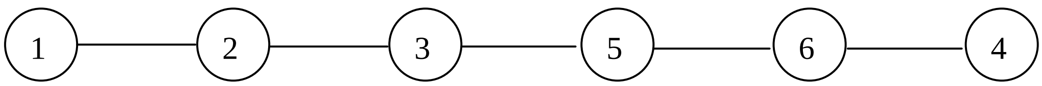


Figure 8.11: Allocation II for Archigraph in example II.

Allocation 3: In solution 2, we allocate the ‘central node’ of the Sociogram to the location of the ‘central node’ of the Archigraph. That is we allocate group a to location B; d to location E; b to A; c to D; e to C; and f to F. Replacing the code of each location with the code of the related faculty means that the Archigraph may be represented as follows:

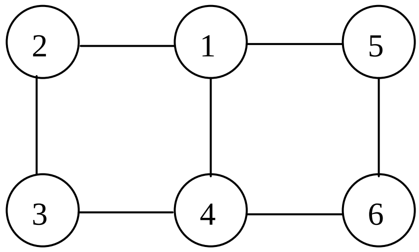


Figure 8.12: Allocation III for Archigraph in example II.

Allocation 4: In solution 2, we allocate the 'central node' of the Sociogram to the location of the 'peripheral node' of the Archigraph. That is we allocate group a to location A; d to F; b to B; c to C; e to D; and f to E. Replacing the code of each location with the code of the related faculty; means that the Archigraph may be represented as follows:

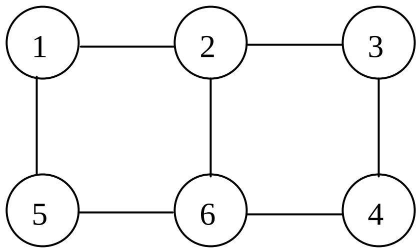


Figure 8.13: Allocation IV for Archigraph in example II.

Step 4. Estimating

Consequently, for all four alternative allocations, the parameters and results of estimation of their Diversity Indexes can be listed in 4 tables, as follows.

Allocation I	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	2, 3	b, c		0	1	0+0	0
Cluster 2	2, 3, 1	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	3, 1, 4	a, c, d	a, c, d	3	3	1+2	18
Cluster 4	1, 4, 5	a, d, e	a, d, e	3	4	1+2	21
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	6, 5	e, f		0	1	0+0	0

Table 8.12: Parameters and results for estimating diversity index for allocation 1 in example II.

Total diversity index for the allocation I is: 0+15+18+21+15+0=69

Allocation II	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 5	b, c, e		0	4	0+0	0
Cluster 4	3, 5, 6	c, e, f		0	3	0+0	0
Cluster 5	5, 6, 4	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	6, 4	d, f	d, f	2	2	1+2	10

Table 8.13: Parameters and results for estimating diversity index for allocation II in example II.

Total diversity index for the allocation II is: 8+15+0+0+15+10=48

Allocation III	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1,2, 5,4	a, b, d, e	a, b, d, e	4	4	1+2	28
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	2	0+0	0
Cluster 4	1,4,3, 6	a, c, e, f	a, c	2	2	1+2	10
Cluster 5	1, 5, 6	a, e, f		0	5	0+0	0
Cluster 6	6, 4, 5	d, e, f	d, e, f	3	2	1+2	15

Table 8.14: Parameters and results for estimating diversity index for allocation III in example II.

Total diversity index for the allocation III is: 28+15+0+10+0+15=69

Allocation IV	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1,2, 5	a, b, e	a, b	2	1	1+2	8
Cluster 2	1,2, 3,6	a, b, c,f	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	2	0+0	0
Cluster 4	4,3, 6	c, d, f	d, f	2	3	1+2	12
Cluster 5	1, 5, 6	a, e, f		0	5	0+0	0
Cluster 6	6,4, 5,2	b, d, e, f	d, e, f	3	2	1+2	15

Table 8.15: Parameters and results for estimating diversity index for allocation IV in example II.

Total diversity index for the allocation IV is: 8+15+0+12+0+15=50

Step 5. Identifying

The Diversity indexes of all allocations are listed in the table below.

	Allocation 1	**Allocation 2**	**Allocation 3**	**Allocation 4**
Total Diversity Index	69	48	69	50

Table 8.16: Comparison of diversity indexes for all allocations in example II.

Allocations 1 and 3 have a higher potential performances of interaction of diverse researchers than the others. Coincidence between the 'central node' of the Sociogram and the 'central node' of the Archigraph seems to cause a higher potential diversity than other allocations, with the same type of architectural plan.

8.4 Using DNAS for design generation

In the previous section, we have constructed our design tool based on two examples to evaluate the best design solution from candidate solutions. In this section we will construct the design tool by considering the generation of the best design from all possible combinations of different forms of schemes and different allocations in these schemes.

8.4.1 Example III. How to generate a design by using DNAS

I. What is the problem?

After the previous two examples, it is helpful for understanding how to use the design tool to identify the best form from alternative forms of plans, or to identify the best allocation from alternative allocations with the fixed form of plan. The President of the university seemed to be satisfied with the advice from DKS. However, the next question is triggered: The design tool does help design evaluation, but how can it help design generation? For instance, if it is decided to design a campus with the highest potential performance of interaction of diverse researchers across different faculties, how can we use our tool to generate an appropriate design?

II. Solving the problem using the design tool

Step 1. Identifying

First is to identify the most basic elements of forms that can be composed into any complex forms. We call these most basic forms 'prototypes'. These prototypes are the most basic and simplest elements of forms to build any complex designs. They are the most basic and the simplest because they cannot be decomposed further without losing their characteristics as a type of basic form, just like those basic chemical elements which can be used to build any complex substance.

The three most basic elements of forms are the ‘Line’, ‘Circle’and ‘Star’. Since ‘Grid’ can be seen as a composition of ‘circle’ and ‘circle’, it is not considered as a kind of prototype. We first identify which is the simplest prototype, ‘Line’, ‘Circle’ or ‘Star’.

The simplest ‘Line’ has a minimum of 3 nodes with the characteristic of line typology. The simplest ‘Circle’ shall have minimum of 3 nodes with a characteristic of circle typology. The simplest ‘Star’ shall have minimal 4 nodes and with a characteristic of star typology. These 3 prototypes are represented in prototypes of Archigraphs:

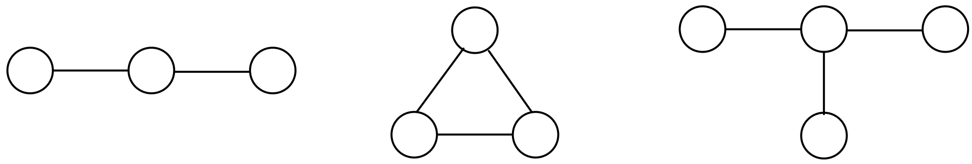


Figure 8.14: Basic prototypes in Archigraph.

Step 2. and 3. Generating and Allocating

The next step is a system to consider all possible different combinations of these ‘Prototypes’. This mechanism has two functions. The first is to combine these ‘Prototypes’ to create all possible combination ‘typologies’ as models of further architectural layouts. The second is to implement all possible different allocations in each typology. A table is made to visualize all the possibilities of combining these ‘prototypes’ into different alternative 6-node ‘Archigraphs’.

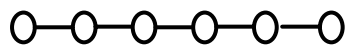
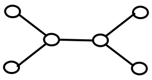
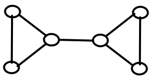
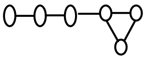
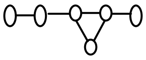
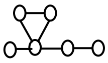
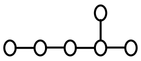
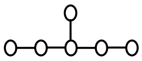
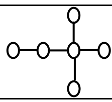
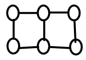
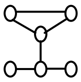
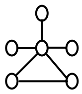
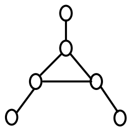
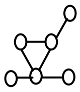
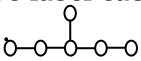
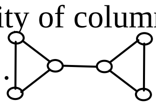
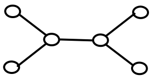
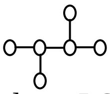
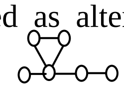
Prototype Combination	Generated Archigraph 1	Generated Archigraph 2	Generated Archigraph 3	Generated Archigraph 4
Line + Line				
Star + Star				
Circle + Circle				
Line + Circle				
Line + Star				
Circle + Star				
Line+ Star +Circle				

Table 8.17: all possible 6 nodes typological combinations between prototype 'Line', 'Star' and 'Circle'

In later discussion we label each of them by their identity of columns and rows in this table. For example  is called typology 'LS2'.  is called typology 'CC1'.

We realize that  and  are actually the same; we thus only choose one to represent both of them. Typology LS4 is what called we a 'Grid' which can be seen here as a combination and superposition of a 4 node 'Line' and a 3 node 'Star'.

We also realize that some combinations can be viewed as alternative ways of combining prototypes to give the same result. For instance:  can be obtained either by combining and overlapping a 'Line' and a 'Circle'; or by combining and overlapping a 'Star' and a 'Line'; or even by combining and overlapping a 'Line', a 'Star' and a Circle. We therefore only categorize it in simplest form, in which it can be identified at first sight. It is hence mostly recognized as a 'Line' and a 'Circle'. In this way, we will have totally 14 unrepeated possible combinations between 2 or 3 kinds of 'prototype'. We understand that for every asymmetrical combination we can generate 6×5×4×3×2×1=720 kinds of allocations, while for every symmetrical combination we can generate 720/2=360 kinds of allocations. Of these 14 kinds of typologies, 8 are symmetrical, and 6 are asymmetrical. The maximum number of possible design solutions we can generate is 6×720+8×360 =7200. Then, how can we know from this enormous number of solutions which one will have the best performance for the potential interaction of diverse researchers?

Certainly, it is not possible to develop designs for such an enormous number of solutions. It would certainly cost too much time and money to hand these solutions to the client. Therefore, from these 7200 solutions, we have to make the best choice according to our target performance. To avoid an endless task of estimation and the introduction of bias in selection, our design tool can help making a scientific estimation on the basis of reasoning and analyzing the target performance. Here, our target performance is the ‘potential interaction of diverse researchers’. Consequently, two steps are necessary to identify the best solution. The **first** is to identify the best allocation for a fixed form of plan. In example II, we have demonstrated within the same typology how can we identify the best allocation. The **second** is to identify the best form of prototypes among these best allocations. We have also illustrated in example I, how can we identify the best types.

Because of limited time and space we will not estimate the best allocation from all possible allocations in every typology, although we have shown this in example II in this chapter. We may leave this task to a computer which will work according to the procedure developed in example II. Suppose the computer has estimated and found the best allocation for every scheme in those 14 generated schemes. The computer gives us 14 best allocations in different typological characteristics. The next step is very easy then. From these 14 different typologies, we then can identify which typology is the best for the potential interaction of diverse researchers, which we have illustrated in example I in this chapter.

Step 4. Estimating

The next step is to estimate from among all these different generated allocations and typologies, which one is expected to have the best performance? Here the target performance is the highest potential interaction of diverse researchers. In this step, the tool plays a similar role to the one it plays in evaluating different design typologies and allocations in the previous two examples. However, this time it has to perform the calculation thousands of times for the thousands of possible solutions in order to identify the best one.

Sub-step 4.1. <u>Identify the best allocation</u> from all possible allocations within the a fixed typology

It is not hard to make a decision between all allocations with the same typology. For example, for typology LC2, it is possible to generate 720 different allocations. From these allocations, the computer can estimate which allocation has the highest diversity potential. The means of estimation is illustrated below in the case of to carrying out an evaluation between two different allocations with the same fixed typology.

Allocation LC2-1:

Allocation LC2-1 is presented in an Archigraph below:

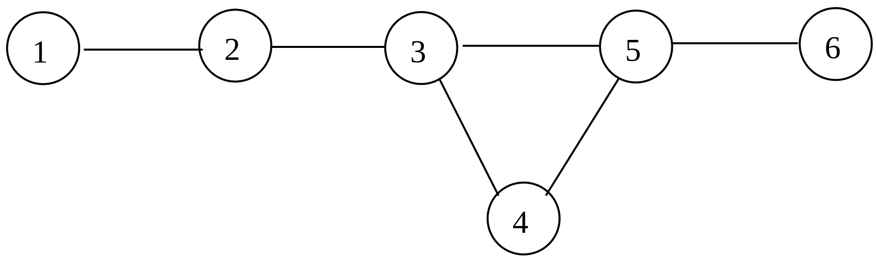


Figure 8.15. Archigraph of allocation LC2-1.

The parameters and results of estimation of the Diversity Indexes can be listed in the table.

Allocation LC2-1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4, 5	b, c, d, e	b, c, d, e	2	1	1+2	8
Cluster 4	3, 4, 5	c, d, e	d, e	2	1	1+2	8
Cluster 5	3, 4, 5, 6	c, d, e, f	d, e, f	3	2	1+2	15
Cluster 6	5, 6	e, f	e, f	2	1	0+0	2

Table 8.18: Parameters and results for estimating diversity index for typology LC2-1 in example III.

Total diversity index for the typology LC 2-1 is: 8+15+8+8+15+2=56

Allocation LC2-2:

Allocation LC2-2 is presented in the Archigraph below:

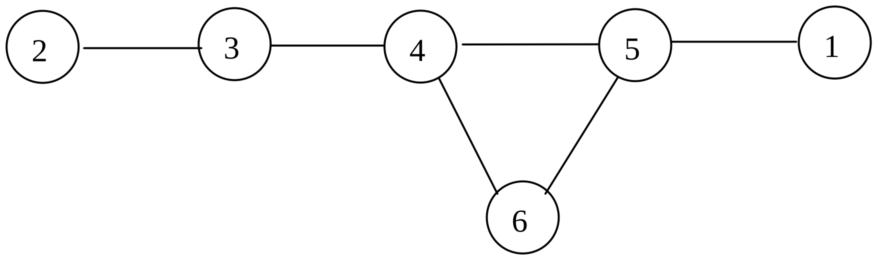


Figure 8.16. Archigraph of allocation LC2-2.

The parameters and result of estimation of the Diversity Indexes can be listed in the table.

Allocation LC2-2	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 5	a, e		0	4	1+2	0
Cluster 2	2, 3	b, c		0	1	1+2	0
Cluster 3	2, 3, 4	b, c, d		0	2	1+2	0
Cluster 4	3, 4, 5, 6	c, d, e, f	d, e, f	3	2	1+2	15
Cluster 5	4, 5, 6, 1	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15

Table 8.19: parameters and result for estimating diversity index for typology LC2-2 in example III.

Total diversity index for the typology LC 2-2 is: 0+0+0+15+15+15=45

Therefore allocation LC2-1 (with Diversity Index 56) is better than allocation LC2-2 (with Diversity Index 45), even though these two different allocations share the same typology. By performing 720 similar estimations for the 720 different allocations (from LC2-1 to LC2-702) with the same typology LC2, we can find the best allocation with the highest potential diversity.

Suppose the computer has identified the best allocation with the highest potential diversity of every kind of typology among those 14 different kinds of possible generated typologies. The next step is to make further estimations and comparison between these 14 typologies.

Sub-step 4.2. Identify the best typology from all kinds of typologies

In this step we consider all the 14 possible 6-node typologies (or forms) mentioned above. For each of these we take the best allocation according to the computer results, and calculate the total diversity index. The results are as summarized below. For each typology we show the best allocation from the computer, the tabulated parameters and results of the estimation of the Diversity Indexes of each cluster, and the Total Diversity Index for that typology.

Typology LL1:

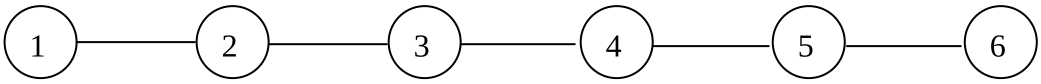


Figure 8.17. Archigraph of typology LL1.

Typology LL1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	4	1+2	0
Cluster 4	3, 4, 5	c, d, e	d, e	2	4	1+2	14
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	5, 6	e, f		0	3	0+0	0

Table 8.20: Parameters and results for estimating diversity index for typology LL1 in example III.

Total diversity index for the typology LL1is: 8+15+0+14+15+0=52

Typology SS1:

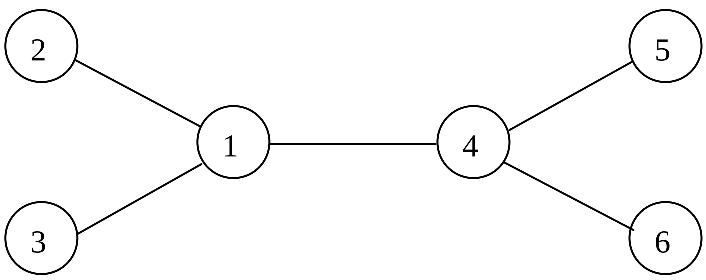


Figure 8.18 Archigraph of typology SS1.

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Typology SS1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 3, 4	a, b, c, d	a, b, c, d	4	3	1+2	24
Cluster 2	1, 2	a, b	a, b	2	1	1+2	8
Cluster 3	1, 3	a, c	a, c	2	2	1+2	10
Cluster 4	1, 4, 5, 6	a, d, e, f	a, d, e, f	4	5	1+2	32
Cluster 5	4, 5	d, e	d, e	2	1	1+2	8
Cluster 6	4, 6	d, f	d, f	2	2	1+2	10

Table 8.21: Parameters and results for estimating diversity index for typology SS1 in example III.

Total diversity index for the typology SS1 is: 24+8+10+32+8+10=92

Typology CC1:

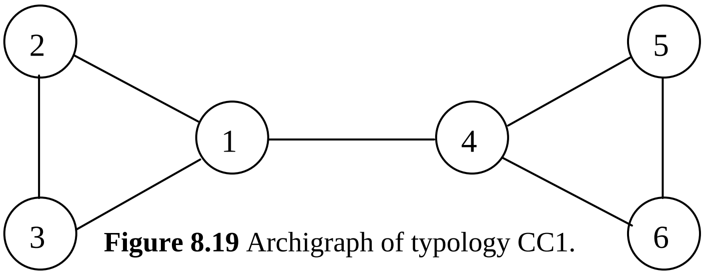


Figure 8.19 Archigraph of typology CC1.

Typology CC1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 3, 4	a, b, c, d	a, b, c, d	4	3	1+2	24
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 4	1, 4, 5, 6	a, d, e, f	a, d, e, f	4	5	1+2	32
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15

Table 8.22: Parameters and results for estimating diversity index for typology CC1 in example III.

Total Diversity index for the solution is: 24+15+15+32+15+15=116

Typology LC1:

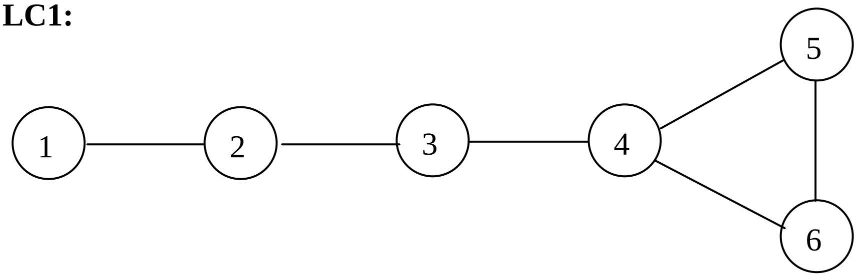


Figure 8.20 Archigraph of typology LC1.

Typology LC1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b, c, d	a, b, c, d	4	3	1+2	24
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	2	1+2	0
Cluster 4	3, 4, 5, 6	c, d, e, f	d, e, f	3	2	1+2	15
Cluster 5	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15
Cluster 6	4, 5, 6	d, e, f	d, e, f	3	2	1+2	15

Table 8.23: Parameters and results for estimating diversity index for typology LC1 in example III.

Total Diversity index for the solution is: 24+15+0+15+15+15=84

Typology LC2:

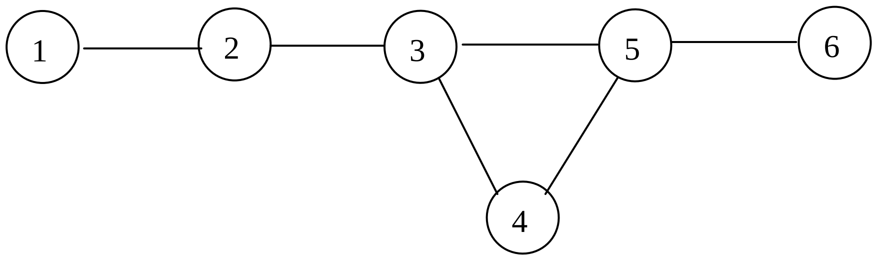


Figure 8.21 Archigraph of typology LC2.

Typology LC2	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4, 5	b, c, d, e	b, c, d, e	2	1	1+2	8
Cluster 4	3, 4, 5	c, d, e	d, e	2	1	1+2	8
Cluster 5	3, 4, 5, 6	c, d, e, f	d, e, f	3	2	1+2	15
Cluster 6	5, 6	e, f	e, f	2	1	0+0	2

Table 8.24: Parameters and results for estimating diversity index for typology LC2 in example III.

Total Diversity index for the solution is: 8+15+8+8+15+2=56

Typology LC3:

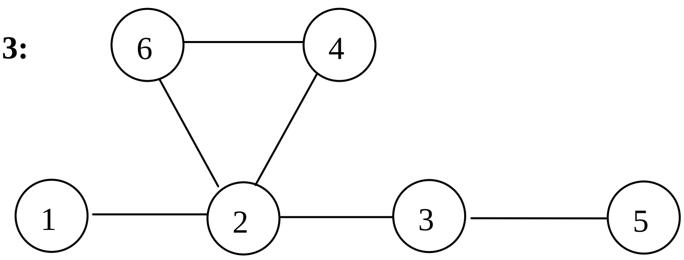


Figure 8.22 Archigraph of typology LC3.

Typology LC3	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3, 4, 6	a, b, c, d, f	a, b, c, d, f	5	5	1+2	40
Cluster 3	2, 3, 5	b, c, e		0	3	1+2	0
Cluster 4	2, 4, 6	b, d, f	d, f	2	4	1+2	14
Cluster 5	3, 5	c, e		0	2	1+2	0
Cluster 6	2, 4, 6	b, d, f	d, f	2	4	1+2	14

Table 8.25: Parameters and results for estimating diversity index for typology LC3 in example III.

Total Diversity index for the solution is: 8+40+0+14+0+14=76

Typology LS1:

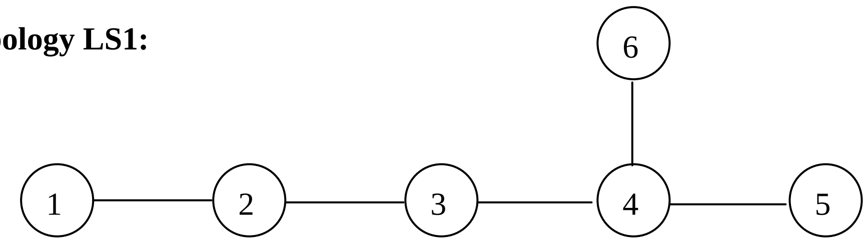


Figure 8.23 Archigraph of typology LS1.

Typology LS1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4	b, c, d		0	4	1+2	0
Cluster 4	3, 4, 5, 6	c, d, e, f	d, e, f	3	2	1+2	15
Cluster 5	4, 5	d, e	d, e	2	1	1+2	8
Cluster 6	4, 6	d, f	d, f	2	2	1+2	10

Table 8.26: Parameters and results for estimating diversity index for typology LS1 in example III.

Total Diversity index for the solution is: 8+15+0+15+8+10=56

Typology LS2:

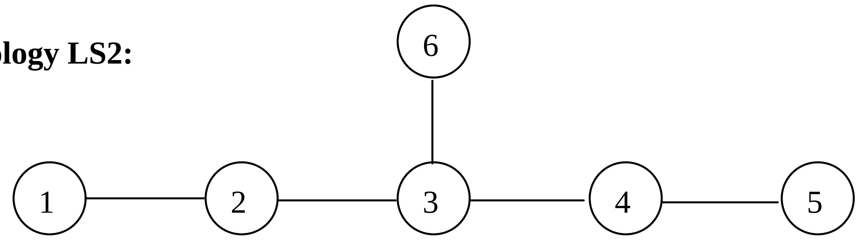


Figure 8.24 Archigraph of typology LS2.

Typology LS2	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4, 6	b, c, d, f	b, c, d, f	2	4	1+2	14
Cluster 4	3, 4, 5	c, d, e	d, e	2	1	1+2	8
Cluster 5	4, 5	d, e	d, e	2	1	1+2	8
Cluster 6	3, 6	c, f	d, f	2	3	1+2	12

Table 8.27: Parameters and results for estimating diversity index for typology LS2 in example III.

Total Diversity index for the solution is: 8+15+14+8+8+12=65

Typology LS3:

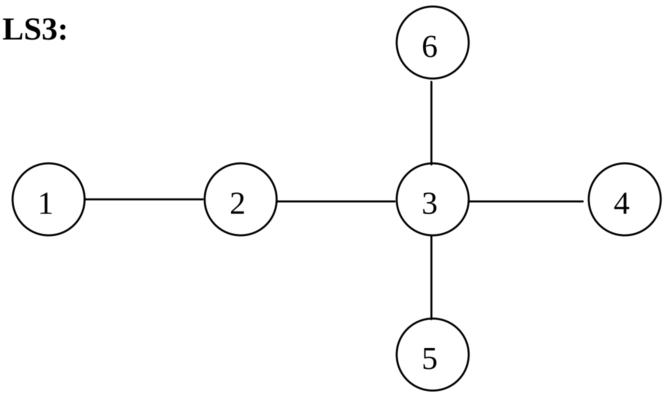


Figure 8.25 Archigraph of typology LS3.

Typology LS3	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3	a, b, c	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 4, 5, 6	b, c, d, e, f	d, e, f	3	2	1+2	15
Cluster 4	3, 4	c, d		0	1	1+2	0
Cluster 5	4, 5	d, e	d, e	2	1	1+2	8
Cluster 6	3, 6	c, f		0	3	1+2	0

Table 8.28: Parameters and results for estimating diversity index for typology LS3 in example III.

Total Diversity index for the solution is: 8+15+15+0+8+0=46

Typology LS4:

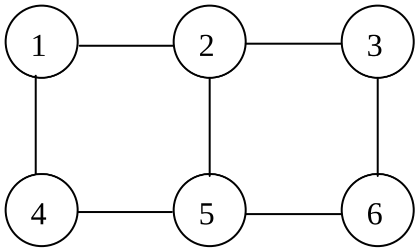


Figure 8.26 Archigraph of typology LS4.

Typology LS4	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 4	a, b, d	a, b, d	3	3	1+2	18
Cluster 2	1, 2, 3, 5	a, b, c, e	a, b, c	3	2	1+2	15
Cluster 3	2, 3, 6	b, c, f		0	4	1+2	0
Cluster 4	1, 4, 5	a, d, e	a, d, e	3	4	1+2	21
Cluster 5	2, 4, 5, 6	b, d, e, f	d, e, f	3	2	1+2	15
Cluster 6	6, 5, 3	e, f, c		0	3	0+0	0

Table 8.29: Parameters and results for estimating diversity index for typology LS4 in example III.

Total Diversity index for the solution 1 is: 18+15+0+21+15+0=69

Typology CS1:

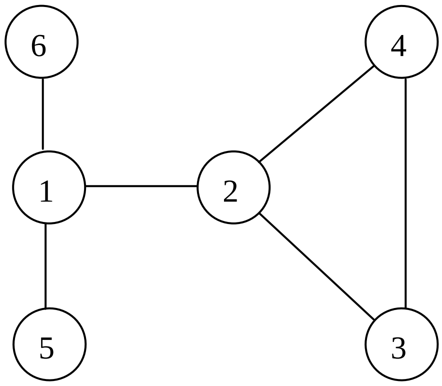


Figure 8.27 Archigraph of typology CS1.

Typology CS1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 5, 6	a, e, f		0	5	1+2	0
Cluster 2	1, 2, 3, 4	a, b, c, d	a, b, c, d	4	3	1+2	24
Cluster 3	2, 3, 4	b, c, d		0	3	1+2	0
Cluster 4	2, 3, 4	b, c, d		0	3	1+2	0
Cluster 5	1, 5	a, e		0	4	1+2	0
Cluster 6	1, 6	a, f	d, f	2	5	1+2	16

Table 8.30: Parameters and results for estimating diversity index for typology CS1 in example III.

Total Diversity index for the solution is: 0+24+0+0+0+16=40

Typology CS2:

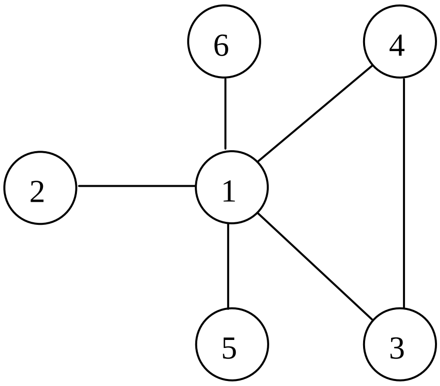


Figure 8.28 Archigraph of typology CS2.

Typology CS2	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 4, 5, 6	a, b, d, e, f	a, b, d, e, f	5	5	1+2	40
Cluster 2	1, 2	a, b	a, b	2	1	1+2	8
Cluster 3	1, 3, 4	a, c, d	a, c, d	3	3	1+2	18
Cluster 4	1, 3, 4	a, c, d	a, c, d	3	3	1+2	18
Cluster 5	1, 5	a, e		0	4	1+2	0
Cluster 6	1, 6	a, f		0	5	1+2	0

Table 8.31: Parameters and results for estimating diversity index for typology CS2 in example III.

Total Diversity index for the solution is: 40+8+18+18+0+0=84

Typology LSC1:

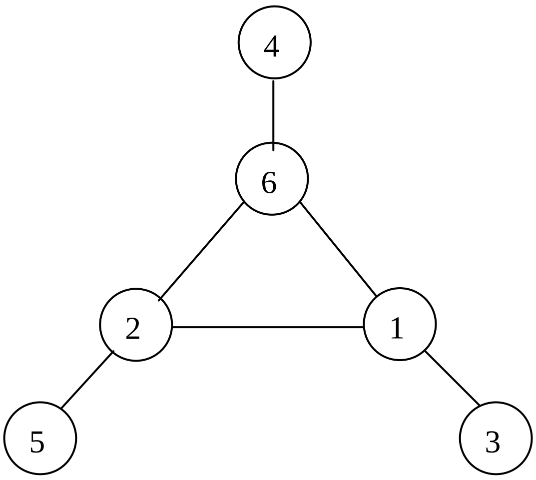


Figure 8.29 Archigraph of typology LSC1.

Typology LSC1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 3, 6	a, b, c, f	a, b, c	3	2	1+2	15
Cluster 2	1, 2, 5, 6	a, b, e, f	a, b, e, f	2	1	1+2	8
Cluster 3	1, 3	a, c	a, c	2	2	1+2	10
Cluster 4	4, 6	d, f	d, f	2	2	1+2	10
Cluster 5	2, 5	b, e		0	4	1+2	0
Cluster 6	4, 6	d, f	d, f	2	2	1+2	10

Table 8.32: Parameters and results for estimating diversity index for typology LSC1 in example III.

Total Diversity index for the solution is: 15+8+10+10+0+10=53

Typology LSC2:

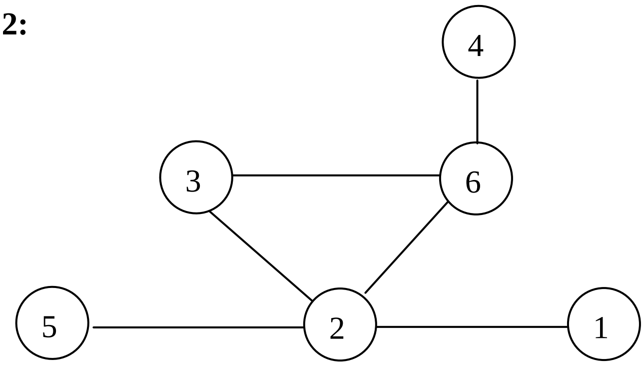


Figure 8.30 Archigraph of typology LSC2.

Typology LSC2	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2	a, b	a, b	2	1	1+2	8
Cluster 2	1, 2, 3, 5, 6	a, b, c, e, f	a, b, c	3	2	1+2	15
Cluster 3	3, 6	c, f		0	3	1+2	0
Cluster 4	4, 6	d, f	d, f	2	2	1+2	10
Cluster 5	2, 5	b, e		0	4	1+2	0
Cluster 6	4, 6	d, f	d, f	2	2	1+2	10

Table 8.33: Parameters and results for estimating diversity index for typology LSC2 in example III.

Total Diversity index for the solution is: 8+15+0+10+0+10=43

Step 5. Identifying

The diversity indexes for all the 14 cases can be summarized in a table, as follows:

Typology	LL1	SS1	CC1	LC1	LC2	LC3	LS1	LS2	LS3	LS4	CS1	CS2	LSC1	LSC2
Diversity Index	52	92	116	84	56	76	56	65	46	69	40	84	53	43

Table 8.34: Comparison of diversity indexes for all typologies in example III.

The conclusion is that typology CC1 has the highest performance of potential diversity, with a diversity index 116, while typology LSC2 has the lowest performance, with diversity index 43. We therefore decide to generate typology CC1 as our final solution to meet the target performance of maximizing the potential interaction of diverse researchers in Innovation Facilities.

Step 6. Translating this best combinational scheme into a real architectural plan.

The best combinational scheme, Archigraph CC1, can be translated into a real architectural plan, which is actually a reverse of the process in the first step in example 1 and example 2. This step can be easily done using a computer and hence is omitted.

8. 5 Conclusion:

In this chapter we have constructed our design tool DNAS and illustrated its practical use by three different examples. We have illustrated the applications of the tool in both evaluating and generating designs using DNAS. In the next chapter we will test the tool ‘DNAS’ by examining a real design case.

CHAPTER 9

TESTING THE TOOL AND PROPOSALS FOR MODIFICATIONS: CASE STUDY 2

Evaluation of the tool using a test case study, and recommendations for future modifications

This chapter will take a real design case to test the tool 'DNAS' which was developed in the previous chapter. By using the design tool, we will analyze the spatial conditions that make one design solution better than another in offering high potential for the interaction of diverse researchers. Possible modifications of the tool are also discussed.

9.1 Description of the design project

Southwestern University of Nationality, founded in 1950 and located in Chengdu, China, is a university mainly for the education of minority students from the Southwestern provinces in China. It is a multi-disciplinary university covering literature, fine art, music, dancing, law, economics and management, engineering, science, life science and biotechnology, computer science and other disciplines. Because of its rapid growth, the university decided to buy another plot of land for an extension. It was planned that the departments of literature, fine art, music, dancing, mathematics and physics would move to the new campus first.

There were several requirements from the administrative staff of the university for designing the new campus. They expected the new campus to be safer, more secure, more flexible for future developments, and more easily managed, to provide a higher density to save on the cost of land, *to facilitate the interaction of more diverse researchers between different departments*, and to meet some other design criteria. After the first run of the competition, two design proposals, those of Fang and another architect, were chosen to enter the second run. In the end Fang's design (Solution 1) was selected. The university administration chose Fang's design on the basis of intuition. However, our tool can be used to identify whether Fang's design has a better performance for the potential 'interaction of diverse researchers' than the alternative design (Solution 3), since this was an important criterion required by the university.

9.2 Testing of the Design Tool

In the previous chapter we have illustrated how to construct our design tool, and given examples of how to use it in three different applications. We have also identified that in the Archigraph Model, nodes are very flexible, and may represent a room, locations in rooms, a group of rooms, a group of buildings, an area in city, a complete city, or, on an even larger scale, a group of cities in regional planning. In the Archigraph Model, nodes can also represent the abstract composition characteristics of the typology of the research target. Here we will test the tool and the model on four levels. The first is the middle level, in which each node mainly represents a building in the plan. The second is a Macro level, in which every node represents a group of buildings. The third is on a micro level, in which every node represents a place in the building. The fourth is on a typological level, in which a node is defined to represent the characteristic of a basic elementary typological form in the plan.

9.2.1 Test at the middle level

To evaluate a design proposal with regard to a high potential for interaction of diverse researchers we have suggested 5 steps:

1. **Translating** building plans into the form of an 'Archigraph', and interactions between agents into the form of a 'Sociogram';

2. **Clustering** to identify clusters of locations, and clusters of users in these clusters of locations;

3. **Tabulating** to identify and rank the extent of differences, considering disciplinary distance and organizational distance;

4. **Estimating** the potential for the interaction of diverse researchers using the equation $D = Nc \times (Dd+Ds)$ to give the diversity index;

5. **Identifying** the proposal solution with the highest potential for the interaction of diverse researchers from a list of candidate schemes.

We will follow these steps using the design tool to see which proposal provides the better performance of diversity.

Step 1. Translating - Representing the Building Plans of both Proposals 1 and 3 as 'Archigraphs'

Given the flexibility of clustering locations in an Archigraph, as mentioned in the previous chapters, these two schemes can be represented on both a macro and a micro level. Here the two proposals are just transferred at the middle level. The plan of design scheme 1 can be transferred to Archigraph 1 and the plan of scheme 3 can be transferred to Archigraph 3.

Figure 9.1: Plan of scheme 1

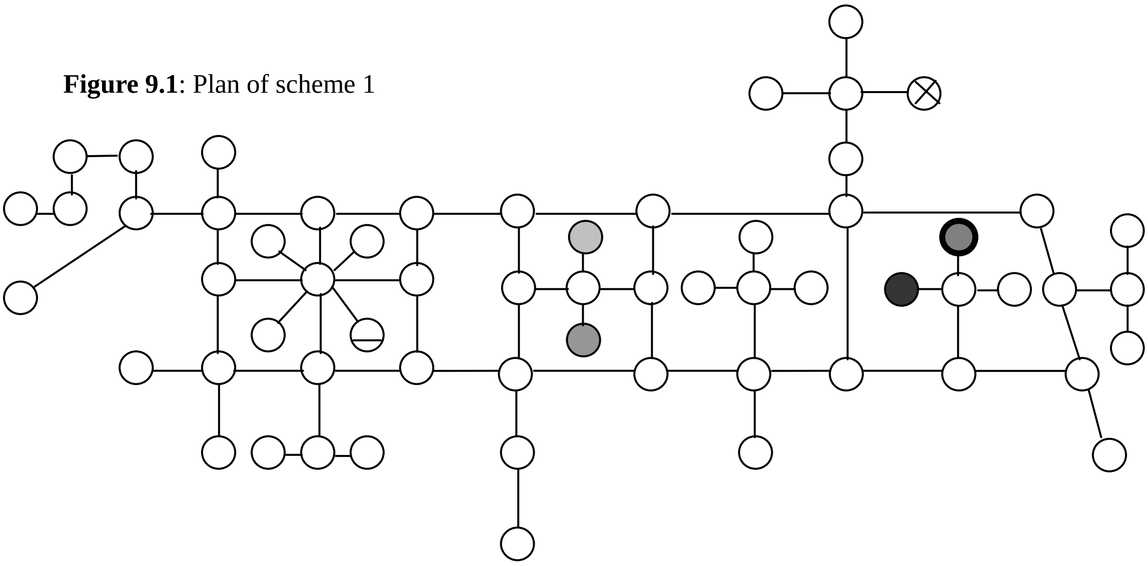


Figure 9.2: Archigraph of Scheme 1. The locations signify the different university departments as assigned by the proposer of Scheme 1, as follows: location 1: mathematics; location 2: physics; location 3: literature; location 4: fine arts; location 5: music; location 6: dance.

: 1,3; : 5,6; : 2; : 4 : Canteen : Museum

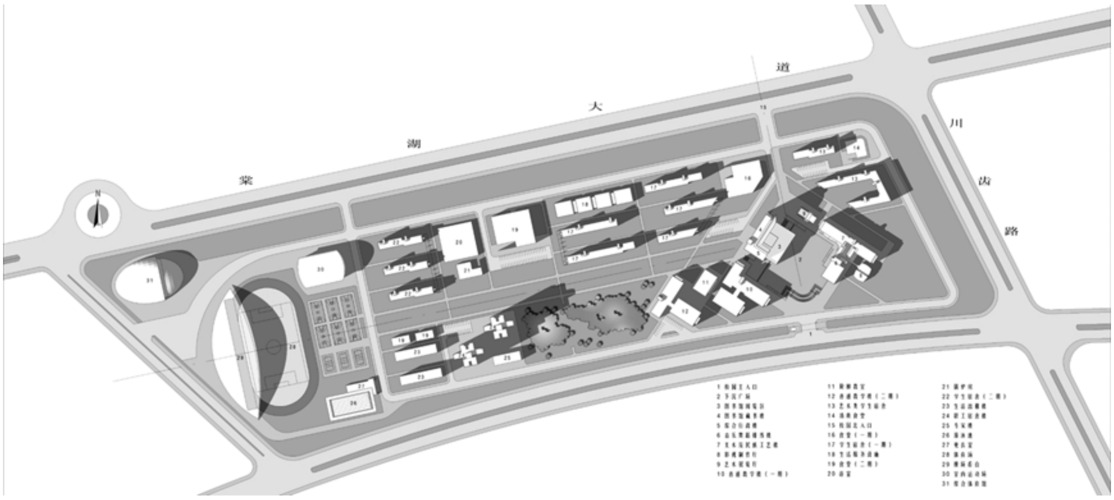


Figure 9.3: Plan of scheme 3

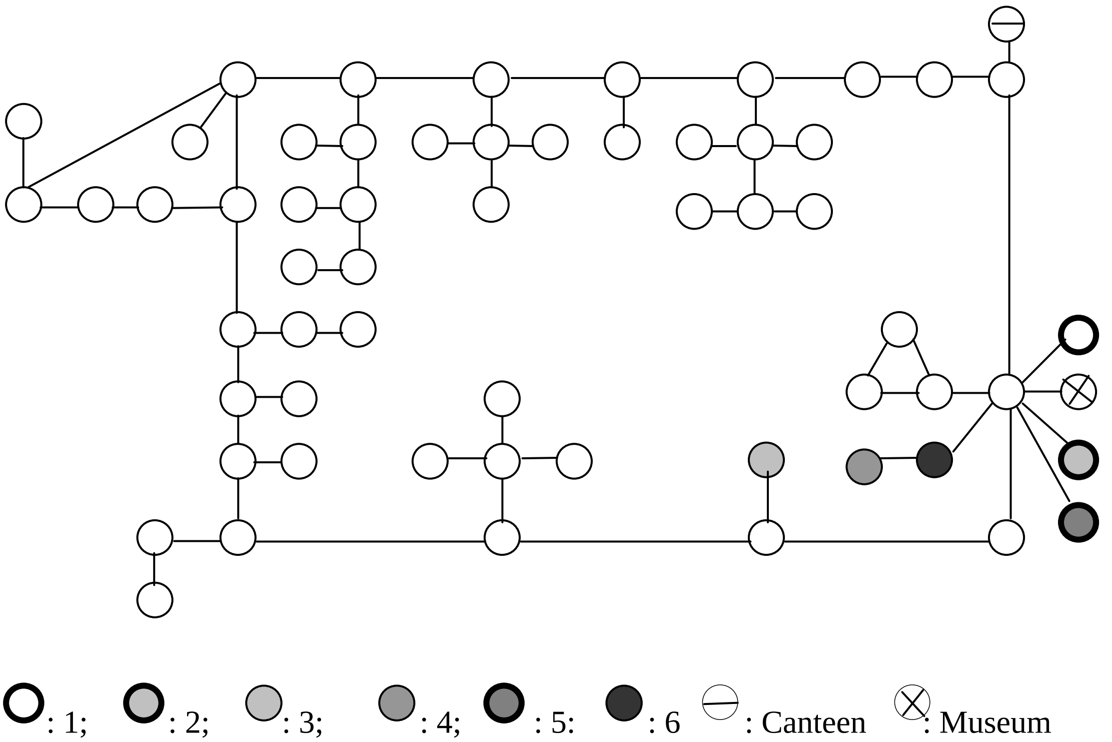


Figure 9.4: Archigraph of scheme 3. The locations signify the different university departments as assigned by the proposer of Scheme 1, as follows: location 1: mathematics; location 2: physics; location 3: literature; location 4: fine arts; location 5: music; location 6: dance.

The Sociogram for the university departments is represented in the graph below, which reveals that c (Faculty of Literature) seems to be the main hub of information flow.

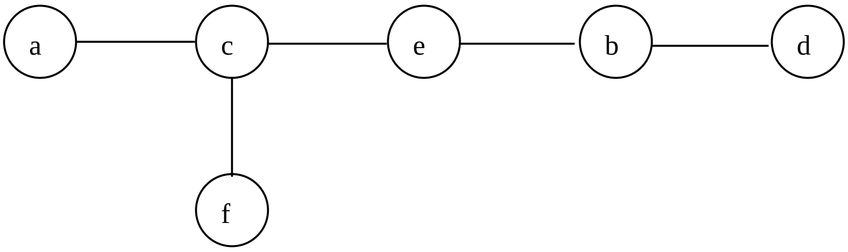


Figure 9.5: Sociogram of the university departments

Nodes represent professors in different departments as follows: node a: mathematics; node b: physics**;** node c: literature**;** node d: fine arts; node e: music; node f: dancing

Step 2. Clustering

In the Sociogram, taking one node as the center of a cluster, only those nodes within a distance of one connection from it are considered be members of this cluster. Accordingly the cluster is labeled in terms of the name of this central node. The identification of all clusters in the Sociogram is presented in the table below:

Name of Cluster	**Cluster A**	**Cluster B**	**Cluster C**	**Cluster D**	**Cluster E**	**Cluster F**
Center	a	b	c	d	e	f
Members	a, c	b, e, d	a, c, e, f	b, d	b, c, e	c , f

Table 9.1: Clusters in the Sociogram.

Similarly, in the Archigraphs, taking one node as center of a cluster, only those nodes within a distance of two connections from it are considered to be members of this cluster (Here, since we are concerned with the important role which the public spaces play in connecting more locations together, we consider a cluster to be defined by a distance of 2 connecting spans instead of the 1 span that we used in the examples in the tool construction). This means that any location node within 2 spans of the defining node is considered a member of that cluster of locations. Accordingly the cluster is labeled in terms of the name of this central node. The identification of all clusters in the Archigraphs is presented in a table below:

Name of Cluster	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**
Center	1	2	3	4	5	6
Proposal 1	1, 3, 5, 6	2, 4	1, 3, 5, 6	2, 4	1, 3, 5, 6	1, 3, 5, 6
Proposal 3	1, 2, 5, 6	1, 2, 5, 6	3	4, 6	1, 2, 5, 6	1, 2, 4, 5, 6

Table 9.2: Table of clusters of locations (within two connections) in every proposal.

Step 3. Tabulating

The main differences between disciplinary distance and between social distance can be listed in the tables below.

Group of researchers in Sociogram	Background of group	Discipline Code
Group a	Mathematics	1
Group b	Physics	2
Group c	Literature	3
Group d	Fine art	4
Group e	Music	5
Group f	Dance	6

Table 9.3: Table of differences between disciplines (the greater the difference between the numerical value of the discipline codes, the sharper the different between disciplines) [1]

	Group a	Group b	Group c	Group d	Group e	Group f
Eccentricity	4	3	3	4	2	4
Centrality node					Yes	
Periphery node	Yes					Yes
Connectivity	1	2	3	1	2	1

Table 9.4: Table of differences in Sociogram

Step 4: Estimating the Diversity index using the Equation: **D = Nc × (Dd+Ds)**

Consequently, for these alternative proposals, the parameters and result for estimating their Diversity Indexes can be listed in 4 tables.

Proposal 1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 2	2, 4	b, d	b, d	2	2	1+1	8
Cluster 3	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 4	2, 4	b, d	b, d	2	2	1+1	8
Cluster 5	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 6	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36

Table 9.5: Parameters and results for estimating diversity index for Scheme 1

Total diversity index for Scheme 1 is: 36+8+36+8+36+36=160

[1] Here is the same as it is in chapter 8 that we only roughly reflect the differences between these disciplines, a precise estimation needs more advanced study and technique.

Proposal 3	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 5, 6	a, b, e, f	b, e	2	4	1+0	10
Cluster 2	1, 2, 5, 6	a, b, e, f	b, e	2	4	1+0	10
Cluster 3	3	c	c	0	0	0	0
Cluster 4	4, 6	d, f		0	1	0+0	0
Cluster 5	1, 2, 5, 6	a, b, e, f	b, e	2	4	1+0	10
Cluster 6	1, 2, 4, 5, 6	a, b, d, e, f	b, d, e	3	4	2+1	21

Table 9.6: Parameters and results for estimating diversity index for Scheme 3

Total diversity index for Scheme 3 is: 10+10+0+0+10+21=51[2]

Step 5. Identifying

According to the results calculated by the design tool, the diversity index of Scheme 1 is 160, while that of Scheme 3 is 51, so Scheme 1 has the higher potential for interaction of diverse researchers. Scheme 1 should therefore be chosen as a better proposal with a higher potential for interaction between diverse researchers across disciplines on the new campus.

	Proposal 1	**Proposal 3**
Sum Diversity Index	160	51

Table 9.7: Comparison of diversity indexes for the 2 schemes

9.2.2 Test at the macro level

We have tested the tool on the middle level of abstraction in which nodes mainly represent buildings. To test the tool on a more abstract level, we will use similar steps and procedure as in the previous test. However, for this test, when we translate the plan into an Archigraph, a node will represent a group of buildings instead of only one building. At this more abstract macro level, parts are seen as a more abstract group as a whole to get its general performance. The idea is from a famous story 'Blind men touch elephant' [3] which illustrates the need to view an object as a whole, ignoring the details.

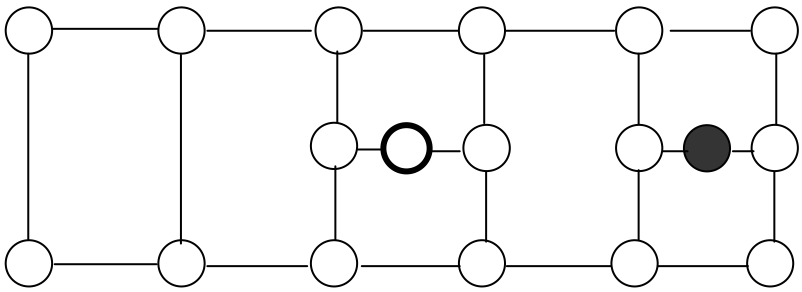
[2] Here we just roughly reflect the total diversity index by summing up all clusters' indices together, however, a precise estimation needs more advanced study and technique. It is the same to note this in the rest tests in this chapter.

[3] A group of blind men tried to identify the shape of an elephant by touching it. Each blind man touched only one part of the elephant but then drew a conclusion about the whole image of an elephant. They one concluded that an elephant is a fan (after touching its ear); another that it was a tree (after touching its leg);

Similarly, to avoid perceiving the elephant as only a fan, a wall, or a pillar, it is better to view it on a more distant, overall level to master the most basic main information. It is thus sometimes useful to ignore local, detailed information in the Archigraph, and to generalize and simplify it into a more global form. This global type may then further simplified as one of the those basic forms named as prototypes in chapter 8. The final step is to evaluate the related performance of this prototype. Scheme 1 looks roughly like a 'Grid' system, and Scheme 3 looks more like a 'Circle' when viewed as a whole. We only retain the key locations where important academic interactions occur and ignore the remaining parts where important academic encounters do not occur.

Step 1. Translating

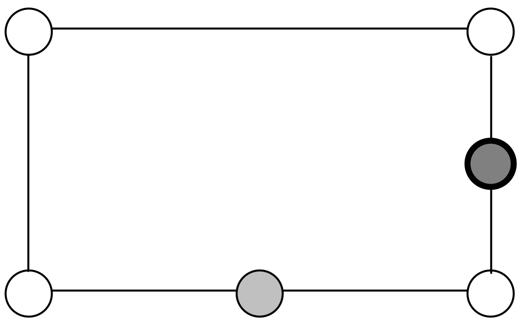
Scheme 1 may be simplified into a global Archigraph as follows:



: location α   : location β (1, 3, 5, 6 are allocated in location α ; 2, 4 are allocated In location β)

Figure 9.6: A global Archigraph for Scheme 1.

Scheme 3 is simplified as a Global Archigraph:



: location λ ; : location Σ (1, 2, 4, 5, 6 are allocated in location λ ; 3 is allocated in location Σ).

Figure 9.7: A global Archigraph for Scheme 3.

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the third that it was a rope (after touching its tail). They hence failed to realize the whole image of the elephant.

The Sociogram of the university is the same as was presented previously in Figure 9.5, since it is unaffected by our different approach to the Archigraph.

Step 2. Clustering

Since the Sociogram is the same as in for the middle level of abstraction, the arrangement into clusters of people will also be the same as that shown in Figure 9.8.

With regard to the clusters of locations, the approach will be the same as for the middle level case (that is defining a cluster by a central node and including nodes within 2 spans.) However, since we are using the global Archigraphs of Figure 9.6 and 9.7, there will be a different in the clusters of locations. The results obtained for Scheme 1 and Scheme 3 are as follows:

Name of Cluster	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**
Center	1	2	3	4	5	6
Scheme 1	1, 3, 5, 6	2, 4	1, 3, 5, 6	2, 4	1, 3, 5, 6	1, 3, 5, 6
Scheme 3	1, 2, 4, 5, 6	1, 2, 4, 5, 6	3	1, 2, 4, 5, 6	1, 2, 4, 5, 6	1, 2, 4, 5, 6

Table 9.8: Table of clusters of locations (within two connections) in the two schemes.

Step 3. Tabulating

Since we are concerned with the same organization and Sociogram as in the previous case, the Discipline codes and Eccentricity, etc are again the same as with the middle level analysis (see Tables 9.3 and 9.4).

Step 4: Estimating the Diversity index using the Equation: **D = Nc × (Dd+Ds)**

Consequently, for the two alternative schemes, the parameters and results for estimating their Diversity Indexes can be listed in 2 tables.

Proposal 1	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 2	2, 4	b, d	b, d	2	2	1+1	8
Cluster 3	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 4	2, 4	b, d	b, d	2	2	1+1	8
Cluster 5	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36
Cluster 6	1, 3, 5, 6	a, c, e, f	a, c, e, f	4	5	2+2	36

Table 9.9: parameters and result for estimating diversity index for proposal 1

Total diversity index for the proposal 1 is: 36+8+36+8+36+36=160

Proposal 3	Location Property	Group Property	Valid Group Property	Nc	Dd	Ds	D
Cluster 1	1, 2, 4, 5, 6	a, b, d, e, f	b, d, e	3	4	2+1	21
Cluster 2	1, 2, 4, 5, 6	a, b, d, e, f	b, d, e	3	4	2+1	21
Cluster 3	3	c	c	0	0	0	0
Cluster 4	1, 2, 4, 5, 6	a, b, d, e, f	c	3	4	2+1	21
Cluster 5	1, 2, 4, 5, 6	a, b, d, e, f	b,d, e	3	4	2+1	21
Cluster 6	1, 2, 4, 5, 6	a, b, d, e, f	b, d, e	3	4	2+1	21

Table 9.10: parameters and result for estimating diversity index for proposal

Total diversity index for the proposal 3 is: 21+21+0+21+21+21=105

Step 5. Conclusion

According to the result calculated by the design tool, the diversity index of Scheme 1 is 160 and that of Scheme 3 is 105, so Scheme 1 has the higher potential for interaction of diverse researchers, even on a more abstract macro level. Scheme 1 should still be chosen as the better proposal with a higher potential for interaction of diverse researchers across disciplines in the new campus.

	Proposal1	**Proposal3**
Sum Diversity Index	160	105

Table 9.11: Comparison of diversity indexes for 2 proposals

9.2.3 Test at the micro level

We have tested the design tool on both middle and macro levels and concluded that Scheme 1 is better than Scheme 3. As mentioned, the cluster is a very flexible concept that can vary according to the scale. Hence the next question arises: what about the evaluation on the micro level? For example, Scheme 1 proposed that the Department of Mathematics and Department of Literature should be put in the same building, labeled 1, 3. Similarly the Departments of Music and Dancing should be allocated to the same building, labeled 5, 6. The problem is, even in the same building will they have the potential to meet each other on the basis of topological constraints? Therefore it seems that a micro level of investigation is necessary. We represent the building plan on a micro level as shown in the Archigraph below:

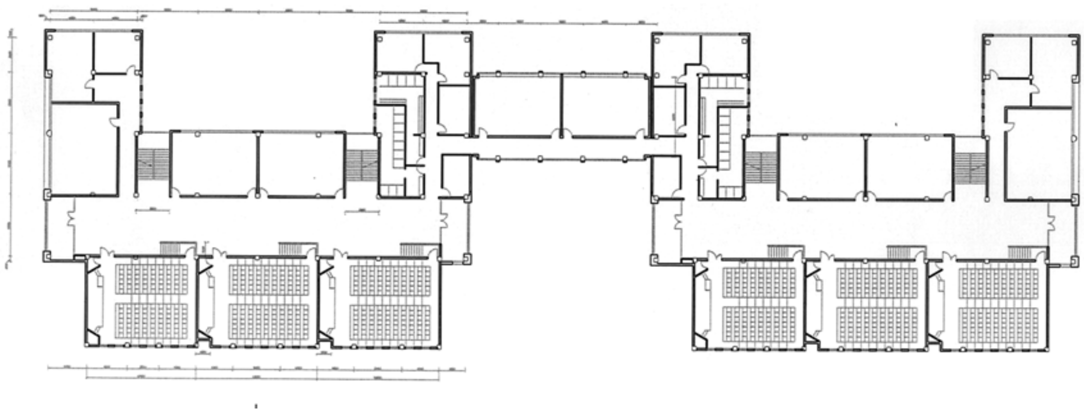

Figure 9.8: Architectural plan of faculties 1 and 3 in Scheme 1.

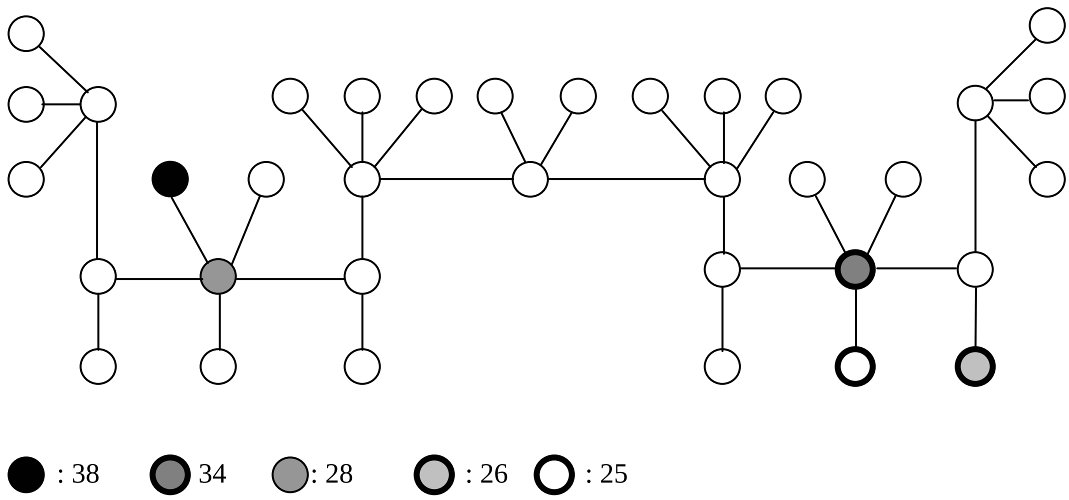

Figure 9.9: A Micro Archigraph of faculties 1 and 3 in Scheme 1. The numbers by the nodes are the room numbers of the key locations assigned to the faculties by the proposer of Scheme 1.

It is clear that Professors from the Department of Mathematics and the Department of Literature generally cannot meet on the second floor, where they are located. However, since the two wings of the building share the public space near the entrances to the two wings on the ground floor, they have the potential opportunity to meet each other in the public space there. Furthermore, they also have chance to meet Professors from the Department of Music and the Department of Dancing in the southern building of this public space, since both northern and southern buildings share this same public space.

However in the alternative Scheme 3 (see Figure 9.4), even at the middle level of abstraction, the Departments of Mathematics, Music and Dancing are in completely different buildings which are far away from each other. The possibility of encounters between them is mainly constrained by the time-distance condition instead of mainly by the topological conditions.

Therefore when we look at the micro level of the Archigraphs, Scheme 1 still has more advantages for creating chances for potential meetings between researchers from different departments.

9.2.4 Test of the typological characteristics

We have tested the tool at micro, middle and macro levels. As mentioned, the Archigraph can also represent the characteristics of the typological synthesis of the plan. We therefore move to a test at the level of typological components in the plans, which can be a bridge connecting the macro performance and the micro performance of the design solutions.

The idea of viewing an object as decomposed into basic types of elementary components is actually inspired by an ancient Chinese story ‘Pao Ding Jie Niu’ (‘The butcher Pao Ding’)[4]. Although our research focuses on neither the way to keep health, nor the way to survive in the society as illustrated in the story, we can adopt the ideas in the ‘invisible framework’ behind the story in architecture and urban planning, and similarly analyze complexity into small basic components. In our research system, both the ‘Sociogram’ and the ‘Archigraph’ are such ‘invisible background frameworks’. So, now we will seek to decompose the Archigraph into some basic types. Every type is an

[4] Pao Ding was the royal butcher of Liang Hui Wang, the ruler of the Liang Kingdom about 2370 years ago in Northern China. Pao Ding killed the cattle so skillfully that the cattle died gradually and even without being aware of pain! ‘Liang Hui Wang’ was surprised and asked how this could be? Pao Ding answered: “when I was just a junior butcher, I saw the whole cattle’s body in my eyes. But years later I had killed so many cows that in my eyes they were no longer whole beings, but a picture of framework of combination of bones and tendons, which I saw as small parts, one by one!” “I thus do not use my eyes anymore but my soul to feel this framework of nodes and linkages, and let my knife just follow the gaps between bones and tendons and decompose them part by part.” “Therefore a junior butcher has to change his knife every month, as he chops, cuts and ignores the existence of this ‘framework’; a senior butcher however changes his knife every year, because he knows some of the ‘framework’, and he just cuts in accordance with it. But I have used the same knife for 19 years, because I only use my knife to ‘draw and follow’ that invisible framework. ”. “Actually, Your Majesty, I kill and cut up the cows according to the ‘Tao’ instead of by skill”. ‘Liang Hui Wang’ commented: “How amazing! Now I understand how to keep my good health”. Sages of Taoism concluded that a wise person survives in the society because he understands the ‘Tao’ in society and just acclimatizes to the ‘pulse and rhythm behind Nature’, so saving both his energy and his life. However, the fool ignores it, and goes on the rampage. He wastes both his energy and life.

elementary 'form' as mentioned in the previous chapter. These 'forms' include 'Line', 'Circle', and 'Star', which provide a way to decompose the whole and give a macro evaluation based on micro instances. We test the performance of these elementary forms, one by one, for their potential diversity in interaction, and thus determine which will promote potential interaction and which will not. The next step is to decompose the entire Archigraph (on both macro and micro levels) into these basic 'forms'. Finally we can estimate the general performance by calculating the total performance from all the sub-performances of these decomposed components. We derive 3 forms as described in chapter 8, similar as the bones and tendons in a cow in the story of 'Pao Ding Jie Niu'.

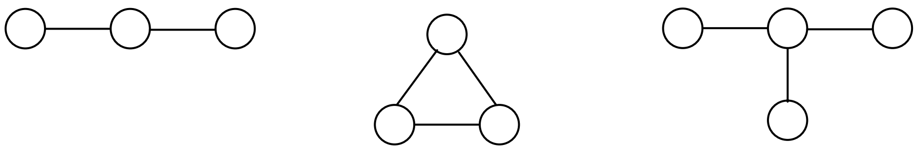

Figure 9.10: Three fundamental elementary 'forms' in Archigraph

We further represent these basic component forms in the plan as labeled nodes. For instance in figure 9.10, the prototype of a 'line' with 3 nodes can be represented as a node labeled 'L3'; the prototype of a 'circle' with 3 nodes can be represented as a node labeled 'C3'; and the prototype of a 'star' with 4 nodes can be represented as a node labeled 'S4'. In this way, we get a overview of the general characteristics of the typological composition of the plan. The next step is to identify the performance of these forms.

The performances for potential interaction of these prototypes have to be discussed with a concrete 'Sociogram' and 'Social Operation Profiles'. Suppose that under a certain 'Sociogram' and 'Social Operation Profiles' a 'Line' will create more chances for meeting and be identified as + (positive), but a 'Star' or a 'Circle' will create fewer such chances and be identified as – (negative). The whole effect on interaction potential can be summed up as follows.

	Line	Circle	Star
Good or Bad for Potential Interaction	+	-	-

Table 9.12: Comparison of potential performance of 'prototypes' in Archigraph

As shown in chapter 7, Figure 7.4, space clusters can be represented on different abstract levels by labels showing their types of forms, and by numbers illustrating how many nodes there are in that form. Similarly, we can decompose both Schemes 1 and 3, represent them in typological views as Archigraphs, and calculate how many 'Lines', 'Circles', and 'Stars' there are in Schemes 1 and 3. Scheme 1 can be represented in a typological Archigraph as follows:

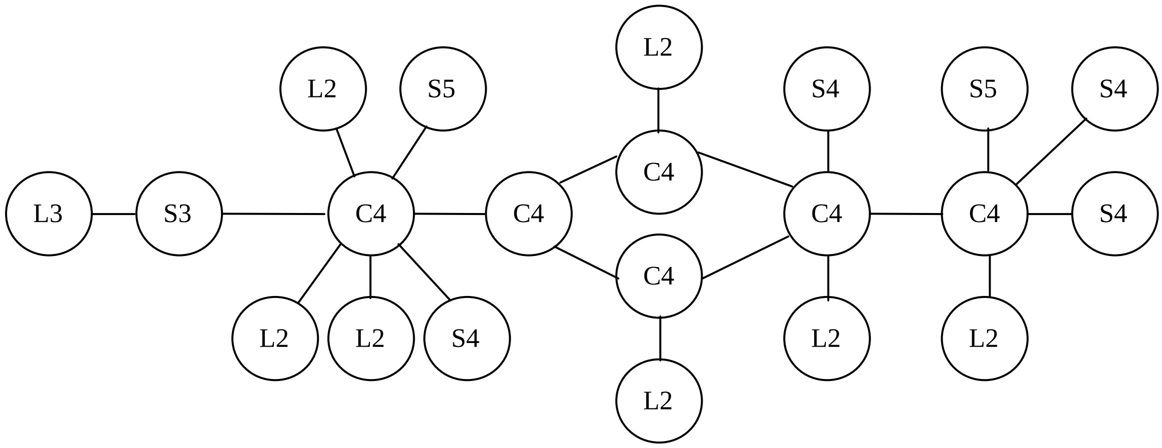

Figure 9.11: The typological components' Archigraph of Proposal 1

Proposal 1 can be represented in a typological Archigraph as:

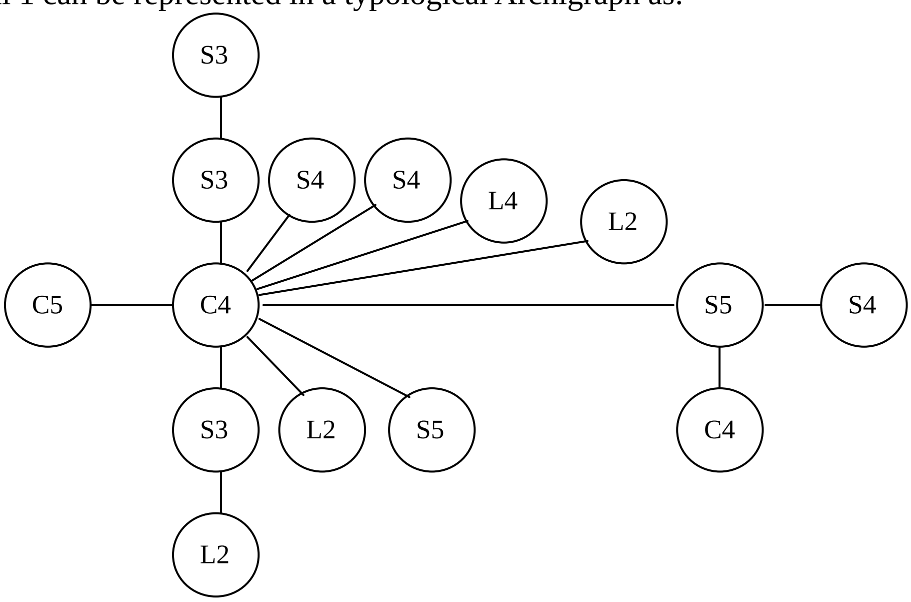

Figure 9.12: The typological components' Archigraph of Proposal 3

We total the numbers of each kind of elementary form in the two schemes and compare them in a table as follows.

	Number of lines	Number of circles	Number of stars
Scheme 1	8	6	7
Scheme 3	4	3	7

Table 9.13: Calculation of number of decomposable 'forms' in Archigraphs for the two schemes

Their total effect on potential interaction can thus be calculated (assuming each kinds of types with different numbers of nodes carries the same weight). In Scheme 1, the total result is 8-6-7=-5[5] and in Scheme 3 the total result is 4-3-7=-6. Therefore, comparing typological forms' potential for promoting encounters between diverse people, Scheme 1 has less negative impact then Scheme 3. It is possible that when the other criteria are considered, the sum of impacts might be different. For instance if 'line' is bad for privacy, but 'circle' and 'star' are good for privacy, then the sum of the impact on privacy in Scheme 1 is –8+6+7=5, while in Scheme 3 it is –4+3+7=6. Scheme 3 might therefore be better for privacy, although it is worse for diversity.

9.3 Possible Modifications

In the previous sections, we have tested the design tool at four levels: the middle level, the macro level, the micro level, and the level of typological component forms. We find that following the basic steps the design tool works correctly to estimate the potential chance of meetings between diverse agents when the topological circulation network is taken as one necessary condition. It is also easy to implement. The result is reliable in the scope defined by topological necessary conditions. However, we have also identified some limitations of the design tool, and hence some ways in which the design tool should be modified.

9.3.1 Modification 1 to the design tool: Necessary and Sufficient

The design tool only helps in estimating which scheme offers the best performance in encouraging high diversity. Some other criteria required by the client university haven't been addressed, such like safety, security, privacy, flexibility, high density, etc (The density controlling seems to be achievable by applying another important tool: 'Space-time Model' proposed by Hägerstrand and his followers). The topological characteristics in an architectural plan potentially determine not only the diversity but also these other factors. As mentioned in the construction of the design tool (Figure 8.5 in chapter 8), there will be a wider scope of concerns and criteria when we look at the topological constraints in the design plan. Taking account of the likely contradictions between these criteria, we need some multi-criteria evaluation methods to see how to

[5] Here we just roughly reflect the total impact by summing up all forms' impacts together. However, a precise estimation needs more advanced study and technique.

keep a sound compromise between the conflicting demands of these criteria. Even for the same criterion as diversity, it's possible that those sub-criteria influencing diversity can have likely contradictions with each other. One choice of method might be the Multiple-criteria Evaluation Method such as the 'ELECTRA' method, which was used by Tzonis and Salama (1978) to make a Multiple-criteria Evaluation between the criteria of community, privacy, and security about thirty years ago. The steps in the design tool can be modified as follows:

Considering multiple-criteria, to evaluate a design proposal with higher potential of interaction of diverse researchers we have suggested 5 steps:

1. **Translating** building plans into the topological representation in an 'Archigraph', and the social relationships among users into a 'Sociogram';

2. **Clustering** to identify clusters of locations, and clusters of users in these clusters of locations;

3. **Tabulating** to identify possible measurements for several criteria at the same time, which should include basic criteria such as: safety, security, privacy, community, diversity, flexibility, etc.

4. **Estimating** the potential performances of each criterion by some equations or algorithm;

5. **Generating** a multiple-criteria evaluation that takes into account all the criteria at the same time;

6. **Identifying** the proposal solution with the best compromise to meet all criteria.

From another perspective, even when we are only concerned with diversity in the design, the topological constraint is only a necessary condition, and is not a sufficient condition. For instance, to enhance diversity in interaction, a space-time model proposed by Hägerstrand also works. If the distance is not short enough, agents do not have chance to meet either. As we transferred information from macro cluster to micro cluster, we concluded in chapter 3 that on a micro level the time-distance constraint seems more effective than topological constraints. We have discussed this point in 9.2.3 when we tested the tool on the micro level. Not only time-space constraints are relevant in enhancing diversity in interaction, but aesthetic aspects also need to be considered. A pleasing work milieu helps in generating diversity, by attracting diverse people, by fostering creativity. The auditive qualities of an environment also influence diversity potential, by making communication easier, by avoiding possible irritating noise. The management skill and strategy also have influence on diversity and innovation on work milieu. A vast arena of more factors can potentially decide diversity and innovation: the people, the organization, the virtual environment, the change processes and more, each of which takes specific form in particular situations. All these can be counted as sub-criteria or criteria influencing the diversity potential, and need to be considered in order to establish sufficient conditions, rather than only concerning the topological layout as one necessary condition. Again, if there are possible potential contradictions between the requirements of these sub-criteria, multiple criteria evaluation still can be employed.

As we have found in chapter 4, the first case study, there are six basic necessary conditions which determine potential meeting probability. Taking account of these criteria and sub-criteria, the influences on diversity can be roughly represented in the following diagram:

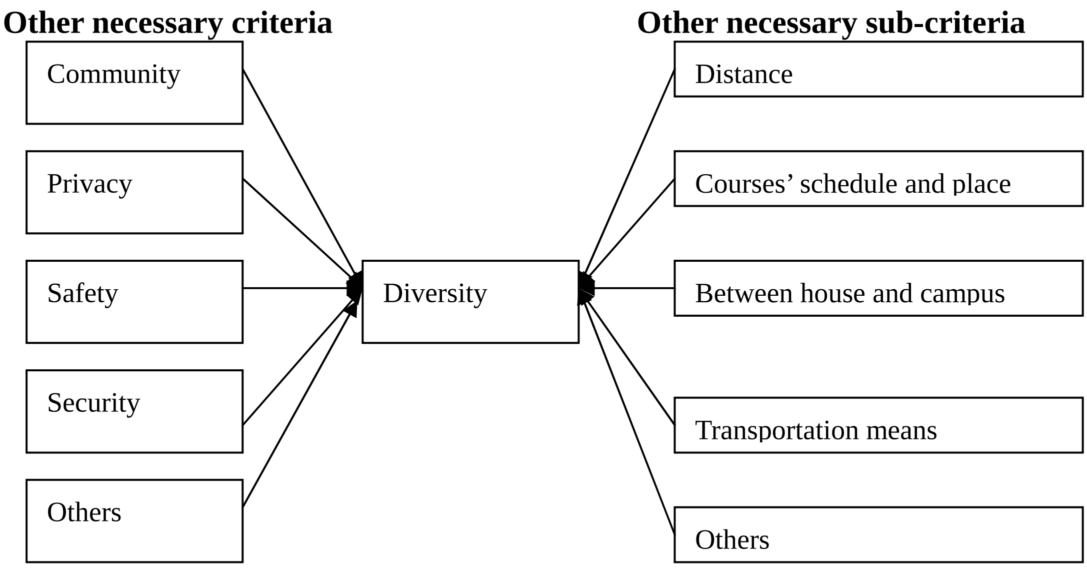

Figure 9.13: Other criteria and sub-criteria that potentially influence diversity

The design tool can be modified by covering more criteria and more sub-criteria, resulting in design judgments made on a more 'sufficient' basis.

9.3.2 Modification 2 of the design tool: Static and Dynamic

In all situations discussed so far, we have taken it as an assumption that all researchers in clusters do not move, that is, they are static clusters. However, in a real situation, they probably will move frequently. They will go to work, and leave for home after work. They will go to the library, go to the canteen, and go to give lectures. The design tool discusses only the diversity potential of static clusters. An additional modification to the design tool should deal with some of the dynamic aspects of diversity in clusters. For instance, if a Professor in the Department of Mathematics (in the eastern wing) goes to a lecture room in the west wing to give a lecture, then he might potentially and occasionally meet a Professor from the Department of Literature during a lecture break outside the entrance to the lecture room. Because his research laboratory is on the opposite side of the building to the classroom, the possibility of meeting is high. As mentioned, if an interaction occurring in a public space in the previous investigation is defines as ‘Static + Static’, then this type of interaction can be called ‘Dynamic + Static’. In addition, suppose the office of the Professor in the Department of Literature is allocated location 38, and he has a lecture in a lecture room in location 25, and the Professor in the Department of Mathematics has a lecture in the a lecture room in location 26 at the same time. Then when they walk to their classrooms they will potentially walk together from location 28 to location 34, and during the walk they have some time to talk and exchange information relevant to innovation. This interaction can be defined as ‘Dynamic+ Dynamic’. Or in another case, if a professor is going through the center of the new campus to take part in a seminar on the opposite side to his department’s building, and another professor is walking across the center as well to go to a concert, then it would be useful to know how to evaluate the potential of a meeting between them.

Zandi-Nia (1992) developed a design tool ‘TOPGENE’ to deal with the design complex. When he evaluated the norm of community he identified the patterns of flows of groups and related them to the topological routes in the plan. Although he didn’t develop a representation system for topological constraints, his method highlights the possibility of measuring potential flow in a topological plan, or in other words, a moving cluster of agents moving on changing cluster of locations. He (1992: 2-29) argues that: “*If we assume that two activities with identical groups are assigned to more than two locations in a building, one may assume that these groups would travel between their assigned locations, and appear at intervening locations. As a result they* *will encounter other groups traveling or residing in those intervening locations and form new groups*".

As an example, let us assume that a professor form the department of mathematics (agent a) and a professor from the department of dancing (agent f) are walking to the canteen. A professor from the department of physics (agent b) and a professor from the department of music (agent e) are walking to the museum. Since in the Sociogram (see Figure 9.5), a and f are in a cluster centered on agent c, and b and e are in the another cluster centered by agent b, the meeting between a and f, and b and e can potentially make a contribution to sustainable innovation. It is easy to be sure of the impact. If two people know each other, then when they meet on the road going somewhere, they will talk on the way. During their conversation they will exchange information, which may potentially promote innovation, especially if they came from different faculties. If they are not in the same cluster, then they may not know each other well, and so are less likely to talk to each other even if they are travelling together for a long way. We then will investigate whether Scheme 1 or Scheme 3 has the better performance in causing a potential meeting.

We have labeled the locations of the canteen and museum in Figures 9.2 and 9.4. In Scheme 1, when agents a (from Department of Mathematics) and f (Dancing) are walking to the canteen, they share a long path which contains 7 nodes along the route if both of them go via the southern route. However, there is 50% probability that one of them goes to the canteen via the alternative route to the north, and they share only a short path, which contains only 2 nodes. The sum of meeting probability can be estimated as: 7 x 50% + 2 x 50% = 4.5. Looking at table 9.3 the discipline difference between the departments which they come from is 6-1=5. The more remote the distances between disciplines in an encounter, the more innovative an idea that might be generated during an encounter. Taking this as a possible weight of the value of their potential meeting, then the weighted value of the total meeting probability is 4.5 x 5 = 22.5. In Scheme 3 however, this chance is lower since these two professors will share a shorter path with only 3 nodes, although there is no alternative path. The total meeting probability can be estimated as 3 x 100%= 3. The value of the weighted total meeting probability is 3 x 5 = 15. The conclusion is thus that Scheme 1 provides a better topological structure that provides a higher value to the probability of a useful encounter in this activity of going to the canteen.

Similarly, we can estimate the value of the probability of an encounter between agent b (physics) and agent e (music) who are going to the museum at the same time. In Scheme 1, they will probably meet on a path of 3 nodes. The total meeting probability can be estimated as: 3 x 100%= 3. The value of the weighted total meeting probability is 3 x 2 = 6. In Scheme 3 they possibly will meet on a path as long as 2 nodes. The sum meeting probability can be estimated as: 2 x 100%= 2. The value of the sum meeting probability is 2 x 2 = 4. Here Scheme 1 provides again a better topological structure that has a higher value of probability of producing a useful encounter in the activity as going to the museum.

The possible modification to the design tool is that the potential for meeting between agents in Innovation Facilities should be observed not only in a static way as it is in the tests of the tool described in this chapter, but also in a dynamic way which can reflect the meeting probability when agents are moving from location to location.

9.4 Conclusion

The design tool does work effectively at several levels: micro, middle, macro, and at the level of basic typological component forms. At these levels it estimates the potential possibility of encounters between agents when the topological constraint is considered as the only necessary condition. However considering the possible limitation of the design tool, there are two main modifications to which we will pay further attention.

First is necessary to cover additional necessary conditions in the tool, as well as the main criteria, and also to consider more sub-criteria in one main criterion. Secondly it is important to consider not only the static situation of the agents but also the dynamic situation of agents who are moving in the topological networks of possible design solutions.

In the next chapter we will summarize the main ideas and the contribution of the research, and we will also discuss the details of the limitations of the research, from which possible further extensions for future research can be outlined.

CHAPTER 10

CONCLUSION AND EXTENSION

Summary of the findings, contributions, limitations, and possible extension of this research

We will conclude by summarizing the major ideas, findings, contributions and limitations of the dissertation. The scope for generalization and possible extensions for future research are discussed in the final section.

10.1 Summary of major ideas in this research

This study aimed to develop a design tool for facilitating the design of Innovation Facilities for which the primary goal is the long-term, sustainable creation of new knowledge. There are three key aspects in which this research work are innovative:

1. the development of a model representing the spatial attributes which constrain face-to-face group interaction in the built environment;

2. to assist the development of the above model, the transfer of concepts and techniques from the domains of economics, regional science, environmental sustainability, and sociology to the domain of spatial design of building complexes;

3. the development of a design tool which can help analyze and generate spatial patterns for buildings which offer necessary spatial conditions for the formation of high diversity clusters.

The research starting from design methodology, employed knowledge from the sociology of scientific innovation, cognitive science, distributed intelligence models, ecological and economic studies, regional science, and the case study method.

It defined the concept of the long-term production of new knowledge drawing from models of 'Sustainable Development' and ecological sustainability. From these models it identified '*Diversity*' of interacting agents as a condition contributing significantly to the production of new knowledge, in addition to the concept of '*Clusters*' of interacting knowledge production agents in a facility. More specifically, the basic features of 'Sustainable Development' were generalized as: the process of increasing or at least maintaining output in a changing environment by means of adaptation. A necessary condition for such adaptation was identified as diversity in physical interactions between knowledge producers forming a cluster. The possibility of achieving such clusters of high diversity through virtual media as opposed to face-to-face interaction was considered, and indeed both are seen to be of value. Hence, although in the very end what is needed in knowledge producing facilities is to combine the advantages of both virtual and physical means of interaction, the research opted to focus on the face-to-face interactions inside a physical place. To measure the diversity of interacting groups in clusters, three steps were suggested:

1. the identification of clustering locations in Innovation Facilities;

2. the identification of interacting users in such clustering locations;

3. the measurement of the diversity of the agents interacting in such clusters.

To give a better understanding of the concepts of diversity and cluster formation related to the physical spatial organization of a facility, the campus of TU Delft was chosen as a case study. To construct the design tool, two models were suggested: the 'Sociogram' to represent interaction between agents within the formal organization of an institution, and the 'Archigraph' to represent locations and potential clusters of interaction within a building complex. On the basis of these two models, the design tool 'DNAS' was proposed. Three examples of possible applications were considered, in order to explore how the tool can be constructed.

Example 1 showed how to evaluate and compare the diversity of interacting researchers in different forms of architectural schemes with similar allocations of room usage. Example 2 demonstrated how to evaluate the diversity of interacting researchers, for different allocations of room usage with the same architectural scheme. Example 3 illustrated how to generate the architectural design solution with the highest potential diversity of interacting researchers, from a large number of combinations of different design types and different allocations of room usage. Two design options from a real design competition in China were taken as a second case study. We compared their 'diversity index' by using the design tool and deduced which one provided the higher diversity potential and so could be considered to be the better solution. Possible modifications of the tool were suggested as a result of this case study.

The following questions were posed in the dissertation and answers were provided for them:

1. What are the necessary conditions for producing the most sustainable systems and which of these apply to sustainable innovation?

2. Why is the interaction of diverse researchers in physical space a necessary condition for enhancing sustainable innovation?

3. How can we develop a systematic design tool to help design facilities with the potential for high diversity in groups interacting in clusters?

4. What does the design tool offer?

5. How might it be examined in order to test it?

6. What are its shortcomings?

7. How can it be developed in the future, so that it can be applied more widely?

10.2 Main results of development for the evaluation and generation of designs

Several key methods have been developed in the course of the research, which can be used in further computation relating to design evaluation and design generation.

I. Procedure used for the evaluation of different building schemes

1. **Representing** building plans in an 'Archigraph',

2. **Representing** agents' interactions in a 'Sociogram';

3. **Clustering** to identify clusters of locations, and to identify clusters of users in these clusters of locations;

4. **Tabulating** to identify and rank the extent of differences, considering disciplinary distance and organizational distance;

5. **Estimating** the potential of diversity of interacting researchers;

6. **Identifying** the project solution with the highest potential for diversity of interacting researchers from a list of candidate schemes.

II. Procedures used for the evaluation of different allocations within a given scheme

1. **Representing** formal interactions between agents in a 'Sociogram';
2. **Representing** building plans in an 'Archigraph';
3. **Clustering** to identify clusters of locations, and to identify clusters of users in these clusters of locations;
4. **Allocating** groups in clusters in an 'Archigraph' to maximize the diversity of interaction by employing information about group difference from the 'Sociogram';
5. **Estimating** the potential for interaction of diverse groups in a given scheme;
6. **Identifying** the allocation of locations topological pattern with the highest potential for diversity of interacting researchers from a list of candidate allocation patterns.

III. Procedure used for design generation:

1. **Identifying** basic types of building schemes such as 'linear', 'circular', and 'Star', according to their topological relationships;
2. **Generating** different design solutions by combining basic topological types of architectural schemes expressed as graphs;
3. **Allocating** different activities and groups of users to the available locations in a topological scheme generated by step 2;
4. **Estimating** the potential for interaction of diverse researchers in a specific location and of a specific topological scheme;
5. **Identifying** the best combination solution, with the highest potential for diversity of interacting researchers, from a list of combinations of different types of topological schemes and different locational allocations within these schemes;
6. **Translating** this best combinational scheme into a real architectural plan (Not covered in this research).

10.3 Limitations of the study

The tool was developed on the basis of examination of a limited case. The cases considered for application and testing were also limited in scope and variety. As a result, care should be taken not to generalize the conclusions too far.

The tool developed does not lead to a final architectural plan. At each step of the tool's development, certain choices were made in order to make the tool feasible, which, however, limit its application. The tool focuses only on controlling, through design, the potential for diversity cluster formation in an architectural plan. However, other aspects can constrain the production of new knowledge in a facility, such as privacy, security, environmental comfort, aesthetic stimulation, etc. These aspects were not considered in this research.

One basic limitation of the tool is that it does not include aspects of time, or a dynamic use of the facility by its users.

In general, the tool tries to focus on the necessary conditions for diversity of interaction in clusters that appear in a Knowledge Production Facilities. It would be a mistake to assume that these necessary conditions are also sufficient conditions. To expect the tool as an 'environmentally deterministic machine' will also lead to mistake.

The tool can be applied widely as a means for reflection and analysis in the pre-conception program phase of the design process. While it can be used safely to assist designers, and also clients and users, by providing a better understanding of a complex building plan, or even more effectively in comparing alternative building plans, it is not intended for use as a deterministic design machine.

10.4 Potential extensions and generalizations of the tool

In future developments, the limitations of the design tool can be overcome in different approaches.

I. A more extensive examination of cases and testing of the conclusions will lead to a more rounded model and more generalized application.

II. A second major extension will be the introduction of time and 'dynamic' use of the facility.

A significant extension of the tool can make use of an important model dealing with innovation and the interaction of people in space over a large, regional scale, known as the Space-time model. As mentioned, the research reported in the previous chapters focused mostly on aspects of topology; Euclidean metrics of distance and time distance were not taken into consideration. However, in a future development of this tool, one can imagine a combination of both a space-time model and our topological representation of locations in space.

Forty years ago, research was initiated by Hägerstrand to develop a model linking spatial and temporal constraints on individual behavior and the diffusion of innovation. Hägerstrand had studied human migration in the 1960s and developed a most influential model. He was convinced that the study of human beings as groups and aggregate populations obscured the true nature of human patterns of movement. He believed that an understanding of disaggregate spatial behavior was paramount. Hägerstrand's paper, “What about People in Regional Science?” published in 1970, challenged traditional beliefs that tended to treat time as an external factor. Hägerstrand stressed the importance of time in human activity and argued that time had a critical importance when it came to fitting people and things together to function in a socio-economic system. Hence, a given location may be near an individual, but if a person cannot allocate enough time to travel to it, spatial proximity alone will not be enough to allow the person to visit it. The time-distance constraint plays an important role in cluster formation. From this we can clearly see how Hägerstrand used the space-time path[1] to demonstrate how human spatial activity is often governed by limitations, and not by independent decisions by spatially or temporally autonomous individuals[2].

Hägerstrand's concept of space-time is significant because it provides a simple way to realize a complex situation in economic geography. Although its inspiration was derived from the study of human migration patterns, it quickly took hold across the social science spectrum[3]. Space-time geography revolutionized the study of

[1] A space-time path represents the path taken by an individual, but any one path is only one of many that can actually be taken by a person in a given amount of time. A space-time "prism" is the set of all points that can be reached by an individual given a maximum possible speed from a starting point in space-time and an ending point in space-time.
[2] He identified three categories of limitations, or "constraints": capability, coupling, and authority. Capability constraints refer to the limitations on human movement due to physical or biological factors.
[3] In 1976, Bo Lenntorp, one of Hägerstrand's associates at Lund University, studied how increased bus services in the city of Karlstad could increase the number of areas within the city that would be accessible to a person given a particular individual "activity program." Three years later, Lawrence Burns further elaborated on the accessibility aspect of the space-time model by demonstrating the impact of altering factors such as differing modes of travel, increased transportation options, and even the time of commuting to work. Throughout the 1980s and 1990s, Hägerstrand's model continued to influence fields ranging from city planning to social equality. In 1991, Harvey Miller from the University of Utah demonstrated how space-time prisms could be applied to modern transportation GIS

transportation accessibility largely because of its ability to represent individual behavior in a reasonably accurate manner. Based on Hägerstrand's space-time prism, Miller (1991) modeled accessibility within GIS systems, and Kwan (1998) compared the relationships and spatial patterns of different measures using network-based GIS procedures.

In addition, Hägerstrand's model also suggests that flows and interaction can be represented in a diagram. Similarly, the model in the research in this thesis has also reflected the potential topological structure in graphs, which makes flows and interaction possible. Besides, there are several aspects of Hägerstrand's spatial model which could form part of a future extension of this tool. The most constructive for future extension is that, using of the space-time geography mapping technique shows spatio-temporal flows and interactions at a much finer level reflecting time-distance constraints, comparing with only employing the topological network in which time-distance is always ignored.

However, in addition, Hägerstrand studied interactions between people in space in terms of how they transmit new knowledge which has already been developed. The new, more inclusive model, has to take that into consideration. It must adapt the Space-time concept to how new knowledge develops. Furthermore, the scale Hägerstrand was concerned with is greater than that of building complexes. Thus, once more, important adaptations have to be made.

III. Focusing on necessary conditions, the empirical basis for the model seems to be insufficient, although the study is grounded mainly on preexisting literature in which arguments are based on an empirical work. The model should be positioned and used in the design process to play out possibilities that might be considered and subjected to reflection and analysis by client groups and professionals alike.

IV. Further on, the design tool can be developed to introduce other criteria which also contribute to the sustainable production of new knowledge such as safety, privacy, security, group identity, environmental comfort, aesthetic stimulation etc.

V. Clearly, the introduction of these other diverse objectives will lead to the need to introduce a method of multiple-criteria design decision-making and evaluation in order to be able to compose an optimum aggregate solution method (Tzonis and Salama, 1973; Shefer and Voogd, 1990).

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systems. Miller pointed out that the two-dimensional footprint of the PPS, known as the "potential path area", or PPA, was conceptually similar to potential paths taken along a network system of arcs and nodes to determine accessible areas for a given location. Several years later, Mei-Po Kwan of Ohio State University demonstrated that space-time models could show disparities in gender accessibility -- even from the same household -- that were invisible in traditional spatial gravity models.

VI. Finally, a most important area for further investigation could be the extension of the present tool to consider not only physical place clusters, but also their combination and interaction with virtual media clusters.

The design tool which was initially developed for facilities for the Sustainable Production of Knowledge can also contribute, if properly adapted, to other domains of similar design complexity and scale, including interior design, industrial design, organizational structure planning, strategic analysis, and economic geographical and regional planning.

10.5 Conclusions

Due to the novelty and complexity of the subject, in addition to sate of the art design and architecture theories, we employed a research method introducing knowledge from social science, ecology, economics, graph theory, cognitive science, and regional science.

A case study was introduced to identify adequacy criteria for the tool. The main aspect derived from the case was the fundamental role the topological organization of a plan plays in constraining the formation of clusters of high diversity. Two models play an important role in the construction of the design tool 'DNAS' (**D**iversity **N**etwork **A**nalysis **S**ystem). The design tool provides possibilities for both evaluation and generation of design solution for 'Sustainable Innovation Facilities', considering some necessary conditions for the possible emergence of clusters of interaction of high diversity. The design tool was tested in a second case study to see how well the tool did and how to improve it.

As it stands, the tool is not to be used in a deterministic way, but more as a device for reflection, evaluation and also inspiration. The tool is open to further modifications and extensions with its basic structure remaining intact.

APPENDIX

Appendix 1: Detailed Data of Case Study 1

Table 4.1: People-Space-Activity-Time of a one-day profile in TU Delft

People / Space-Activity Time	S1	S2	S3	S4	S5	S6
1st session 8:45-9:30	Taking course in L1	On the way to L2	Taking course in L3	Studying at home	Taking course in L5	Taking course in L6
Break 1 9:30-9:45	Coffee in corridor of L1	Coffee in lobby of L2	Walking along the corridor	On the way to L7	Walking round in L5	Walking along the corridor
2nd session 9:45-10:30	Taking course in L1	Computer room of L2	Taking course in L3	Reading in L7	Taking course in L5	Taking course in L6
Break 2 10:30-10:45	On the way to L6	Computer room of L2	Walking along the corridor	On the way to L4	On the way to library L5	Walking along the corridor
3rd session 10:45-11:30	Taking course in L6	Computer room of L2	Taking course in L3	Reading In Library L4	Reading in library L5	Reading in library of L6
Break 3 11:30-11:45	Walking in L6	Computer room of L2	Walking along the corridor	Reading In Library L4	Reading in library L5	Walking along the corridor
4th session 11:45-12:30	Taking course in L6	Computer room of L2	Taking course in L3	Reading in Library L4	Reading in library L5	Reading in library of L6
Lunch-time 12:30-13:30	Lunch in L8	lunch in canteen of L2	lunch in canteen of L3	lunch in canteen of L4	Lunch in L8	Lunch in canteen of L6
5th session 13:45-14:30	Reading in L7	Computer room of L2	Reading in Library of L3	Reading in Library L4	Studio in L5	Exercise in Sports center
Break 4 14:30-14:45	In L7	Walking to Library of L2	Reading in Library of L3	Reading in Library L4	Studio in L5	Coffee in Sports center
6th session 14:45-15:30	Reading in L7	Reading in Library of L2	Reading in Library of L3	Reading in Library L4	Studio in L5	Exercise in Sports center
Break 5 15:30-15:45	Shopping in center	On the way to L7	Walking to Library of L3	Reading in Library L4	Walking in L5	Studying in Library of L4
7th session 15:45-16:30	Shopping in center	Reading in L7	Reading in Library of L3	Reading in Library L4	Studio in L5	Studying in Library of L4
Break 6 16:30-16:45	Studying at home	Reading in L7	Reading in Library of L3	On the way home	Studio in L5	Studying in Library of L4
8th session 16:45-17:30	Studying at home	On the way to home	Reading in Library of L3	Studying at home	Studio in L5	Studying in Library of L4

Table 4.2 The one-day profile represented by Activity Code and Location Code in TU Delft

People / Space-Activity Time	S1	S2	S3	S4	S5	S6
1st session 8:45-9:30	A1 in L1	A2 in L2	A1 in L3	A2 in L9	A1 in L5	A1 in L6
Break 1 9:30-9:45	A3 in L1	A3 in L2	A4 in L3	A4 from L9 to L7	A4 in L5	A4 in L6
2nd session 9:45-10:30	A1 in L1	A2 in L2	A1 in L3	A2 in L7	A1 in L5	A1 in L6
Break 2 10:30-10:45	A4 from L1 to L6	A2 in L2	A4 in L3	A4 from L7 to L4	A4 in L5	A4 in L6
3rd session 10:45-11:30	A1 in L6	A2 in L2	A1 in L3	A2 in L4	A2 in L5	A2 in L6
Break 3 11:30-11:45	A4 in L6	A2 in L2	A4 in L3	A2 in L4	A2 in L5	A4 in L6
4th session 11:45-12:30	A1 in L6	A2 in L2	A1 in L3	A2 in L4	A2 in L5	A2 in L6
Lunch-time 12:30-13:30	A4 from L6 to L8, A3 in L8, A4 from L8 to L7	A3 in L2	A3 in L3	A3 in L4	A4 from L5 to L8, A3 in L8, A4 from L8 to L5,	A3 in L6, A4 from L6 to L9
5th session 13:45-14:30	A2 in L7	A2 in L2	A2 in L3	A2 in L4	A2 in L5	A5 in L9
Break 4 14:30-14:45	A4 in L7	A2 in L2	A2 in L3	A2 in L4	A2 in L5	A5 in L9
6th session 14:45-15:30	A2 in L7	A2 in L2	A2 in L3	A2 in L4	A2 in L5	A5 in L9
Break 5 15:30-15:45	A4fromL7 to L9	A4 from L2to L7	A4 in L3	A2 in L4	A4 in L5	A4 from L9 to L4
7th session 15:45-16:30	A5 in L9	A2 in L7	A2 in L3	A2 in L4	A2 in L5	A2 in L4
Break 6 16:30-16:45	A4 from L9 to L9	A2 in L7	A2 in L3	A4 from L4 to L9	A2 in L5	A2 in L4
8th session 16:45-17:30	A2 in L9	A4 from L7 to L9	A2 in L3	A2 in L9	A2 in L5	A2 in L4

Table 4.3: Profiles of (potential) meetings between different students (All the other time phases during which no meeting occured are ignored)

Table 4.3a: Meetings during Break 2: 10:30-10:45

	S2	S3	S4	S5	S6
S1			Yes		Yes
S2					
S3					
S4					
S5					

Table 4.3b: Meeting during Break 3: 11:30-11:45

	S2	S3	S4	S5	S6
S1					Yes
S2					
S3					
S4					
S5					

Table 4.3c: Meeting during Lunch-time: 12: 30-13:30

	S2	S3	S4	S5	S6
S1				Yes	Yes
S2					
S3					
S4					
S5					

Table 4.3d: Meeting during Break 5: 15:30-15:45

	S2	S3	S4	S5	S6
S1	Yes				Yes
S2					
S3					
S4					
S5					

Table 4.3e: Meetings during 7th course: 15:45-16:30

	S2	S3	S4	S5	S6
S1					
S2					
S3					
S4					Yes
S5					

Table 4.3f: Meetings during Break 6: 16:30-16:45

	S2	S3	S4	S5	S6
S1			Yes		
S2					
S3					
S4					
S5					

Table 4.4 Meeting Profile Summary Table

People / **Space-Activity Time**	**Who** had to the potential to meet whom?	**When**	**Where**	**How**
10:30-10:45 Break 2	S1 and S4 S1 and S6	10:30-10:45 10:30-10:45	On main road of campus Inside L6 (Faculty)	Short & informal Short & informal
11:30-11:45 Break 3	S1 and S6	11:30-11:45	Inside L6 (Faculty)	Short & informal
12:30-13:30 Lunch-time	S1 and S6 S1 and S5	12:30-13:30 12:30-13:30	Inside L6 (Faculty) Inside L8 (Faculty)	Short & informal Long & informal
15:30-15:45 Break 5	S1 and S6 S1 and S2	15:30-15:45 15:30-15:45	On main road of campus On main road of campus	Short & informal Short & informal
15:45-16:30 7th session	S4 and S6	15:45-16:30	In L4 (library)	Long & formal
16:30-16:45 Break 6	S1 and S4	16:30-16:45	On road of campus	Short & informal

Table 4.5 Activity Profile Table

People / **Time-phase of potential meeting**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Break 2 10:30-10:45	A4 from L1 to L6	A2 in L2	A4 in L3	A4 from L7 to L4	A4 in L5	A4 in L6
3rd session 10:45-11:30	A1 in L6					A2 in L6
Break 3 11:30-11:45	A4 in L6					A4 in L6
4th session 11:45-12:30	A1 in L6					A2 in L6
Lunch-time 12:30-13:30	A4 from L6 to L8, A3 in L8, A4 from L8 to L7	A3 in L2	A3 in L3	A3 in L4	A4 from L5 to L8, A3 in L8, A4 from L8 to L5,	A3 in L6, A4 from L6 to L9
Break 5 15:30-15:45	A4fromL7 to L9	A4 from L2to L7	A4 in L3	A2 in L4	A4 in L5	A4 from L9 to L4
7th session 15:45-16:30	A5 in L9	A2 in L7	A2 in L3	A2 in L4	A2 in L5	A2 in L4
Break 6 16:30-16:45	A4 from L9 to L9	A2 in L7	A2 in L3	A4 from L4 to L9	A2 in L5	A2 in L4
8th session 16:45-17:30	A2 in L9	A4 from L7 to L9	A2 in L3	A2 in L9	A2 in L5	A2 in L4

Table 4.6 Meeting Profile Table
(D + D means Dynamic + Dynamic meeting; D+S means Dynamic + Static meeting; S+S means Static + Static meeting)

People / Space-Activity Time	Who potentially met whom?	How long did the potential meeting last?	Where?	What kinds of means?	Possibility of meeting	Quality of meeting
10:30-10:45 Break 2	S1 and S4 S1 and S6	2 seconds 5 minutes	Between L8 to L4; In L6	D + D D + D	Low High	Low High
11:30-11:45 Break 3	S1 and S6	3-5 minutes	Inside L6	All kinds	Medium	Medium
12:30-13:30 Lunch-time	S1 and S6 S1 and S5	1.5 minutes 1 minute + 30 minutes	Between L6 and L8 Between L6 and L8 In L8	D + D D + D S + S	Medium High	Medium High
15:30-15:45 Break 5	S1 and S6 S1 and S2	2 seconds 2 seconds	Between L7 and L9 Between L7 and L9	D + D D + D	Low Low	Low Low
15:45-16:30 7th session	S4 and S6	0-45 minutes	In L4	S + S	Medium	Medium
16:30-16:45 Break 6	S1 and S4	0-10 minutes	In L9	All kinds	Low	Low

Table 4.7 Time by bicycle between locations on campus(unit: seconds)

	Aerospace Eng.	Archi-tecture	Civil Eng.	Electrical Eng.	Industrial Design	Techn'gy and Manag't	Library	Aula
Aerospace Engineering		344	458	434	614	483	693	612
Architecture	344		114	90	270	360	343	262
Civil Engineering	458	114		81	261	246	229	148
Electrical Engineering	434	90	81		180	165	178	97
Industrial Design	614	270	261	180		114	196	115
Technology Management	483	360	246	165	114		203	122
Library	693	343	229	178	196	203		81
Aula	612	262	148	97	115	122	81	

Table 4.8 Time on foot between locations on campus (unit: seconds)

	Aerospace Eng.	Archi-tecture	Civil Eng.	Electrical Eng.	Industrial Design	Techn'gy and Manag't	Library	Aula
Aerospace Engineering		774	1031	977	1381	1087	1559	1377
Architecture	774		257	203	608	810	772	590
Civil Engineering	1031	257		182	587	554	515	333

	Aerospace Eng.	Archi-tecture	Civil Eng.	Electrical Eng.	Industrial Design	Techn'gy and Manag't	Library	Aula
Electrical Engineering	977	203	182		405	371	401	218
Industrial Design	1381	608	587	405		257	441	259
Technology Management	1087	810	554	371	257		457	271
Library	1559	772	515	401	441	457		182
Aula	1377	590	333	218	259	271	182	

Table 4.9 Answers to Questionnaires

People / **Answers**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Answer to question 1	L4	L8	L7	Home	L7	City center
Answer to question 2	3-4 hours	3-4 hours	1-2 hours	3-4 hours	2-3 hours	2-3 hours
Answer to question 3	Meeting friends at home	Go to the city center	Meeting friends in bar	Sleeping at home	Go to Sports center	Meeting friends in club

Table: Answers to investigated questions

Table 4.10 Time spending on different activities by different students (Units: minutes, percentages)

People / Time Budget / Activities	**S1** **481**	**S2** **493**	**S3** **510**	**S4** **510**	**S5** **510**	**S6** **510**
A1	180 37%	0	180 35%	0	90 18%	90 18%
A2	135 28%	375 76%	210 41%	405 79%	315 62%	195 38%
A3	72.5 15%	60 12%	60 12%	60 12%	46 1%	45 1%
A4	93.5 19%	58 12%	60 12%	45 1%	59 1%	75 15%
A5	0	0	0	0	0	105 21%

Table 4.11 Time spending in different places by different students (Units: minutes, percentages)

People / Time Budget / Activities	**S1** **525**	**S2** **525**	**S3** **525**	**S4** **525**	**S5** **525**	**S6** **525**
L1	105 20%	0	0	0	0	0
L2	0	390 17%	0	0	0	0
L3	0	0	525 100%	0	0	0
L4	0	0	0	345 66%	0	105 20%
L5	0	0	0	0	450 86%	0

People / Time Budget Activities	**S1** **525**	**S2** **525**	**S3** **525**	**S4** **525**	**S5** **525**	**S6** **525**
L6	105 20%	0	0	0	0	270 51%
L7	105 20%	60 11%	0	45 9%	0	0
L8	55 10%	0	0	0	51 10%	0
L9	90 17%	45 9%	0	90 17%	0	105 20%
Between Locations in Campus	13 2%	15 3%	0	15 3%	9 2%	0

Notes on meetings for the 9 phases during which meetings occurred
Time Phase 4. 10:30-10:45 Break 2
During break 2, S1 was moving from L1 to L6; S2 was doing A2 in L2; S3 was doing A4 in L3; S4 was moving from L7 to L4; S5 was doing A4 in S5; S6 was doing A4 in S6.
S1 and S4 could potentially meet on the road between L8 and L4, although they were moving in opposite directions and so they might only have chance say hello to each other. The meeting was 'Dynamic + Dynamic', which means both sides were moving during the meeting. S1 could potentially meet S6 inside L6, since both them were doing A4. It is also 'Dynamic + Dynamic'. This process could be represented in a simplified map of Campus TU Delft.

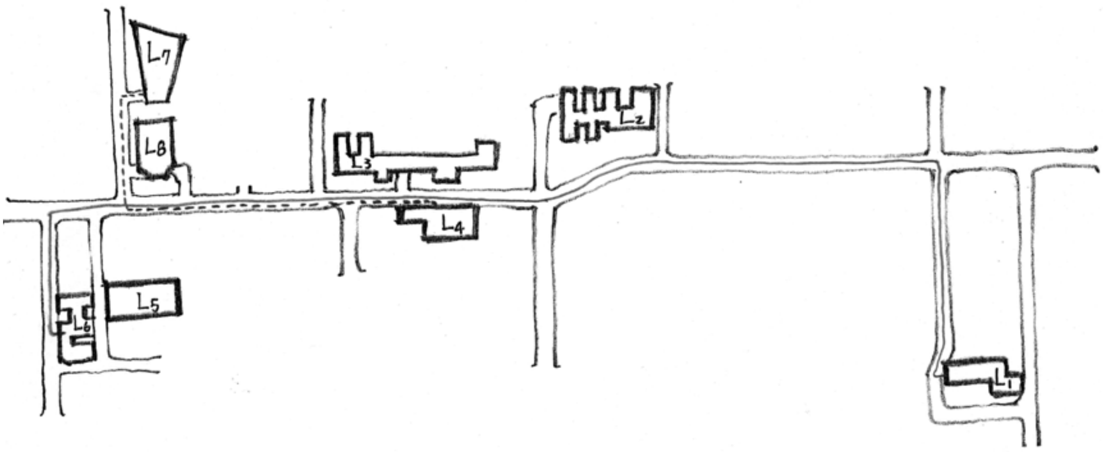

Figure 4.16
Diagram illustrating movements during time phase 4 (slim line is movement of S1, dotted line is movement of S4)

Time Phase 5. 10:45-11:30 3rd session
S1 was doing A1 in L6; S6 was doing A2 in L6. They were doing different things, even though in the same building, and so they would not meet. So no meeting occurred.

Time Phase 6. 11:30-11:45 Break 3
S1 was doing A4 in L6; S6 was also doing A4 in L6. They were doing the same things and in the same building. So it was very possible for them to meet each other in the corridor or some other public place inside L6. The meeting could be D+D, S+S, or D+S.

Time Phase 7. 11:45-12:30 4th session
S1 was doing A1 in L6; S6 was doing A2 in L6. They were doing different things, even though in the same building, so they would not meet. So no meeting occurred.

Time Phase 8. 12:30-13:30 Lunch-time

This phase was the most dynamic and dramatic one of the whole day's campus life. Because many students were moving for lunch, changing course activities, returning home, or coming from home.
When S1 was moving from L 6 to L8, S1 might meet S6 who was leaving L6 to go home. Later on the way to L8, S1 might meet S5 who was moving from L5 to L8 to have lunch. The first potential meeting was 'D+D'. The second one was first 'D+D', but later when S1 and S5 had lunch together in L8, it was 'S+S'. This process can be represented in a simplified map of Campus TU Delft.

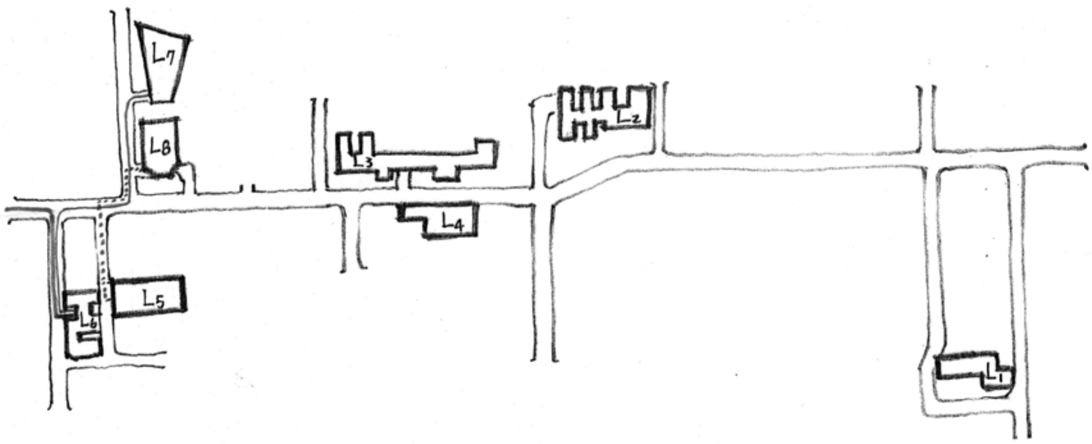

Figure 4.17
Diagram describing movements during time phase 4 (slim line is movement of S1, dotted line is movement of S4, bold line is movement of S6)

Time Phase 12. 15:30-15:45 Break 5
During this time, S1 was moving from L7 to L9, S2 was moving from S2 to S7, S6 was moving from L9 to L4. Although S1 and S6 met on the road, they were moving in opposite directions. Hence they met but for too short a time to have a meeting. The same thing occurred between S1 and S2. This process can be represented in a simplified map of Campus TU Delft.

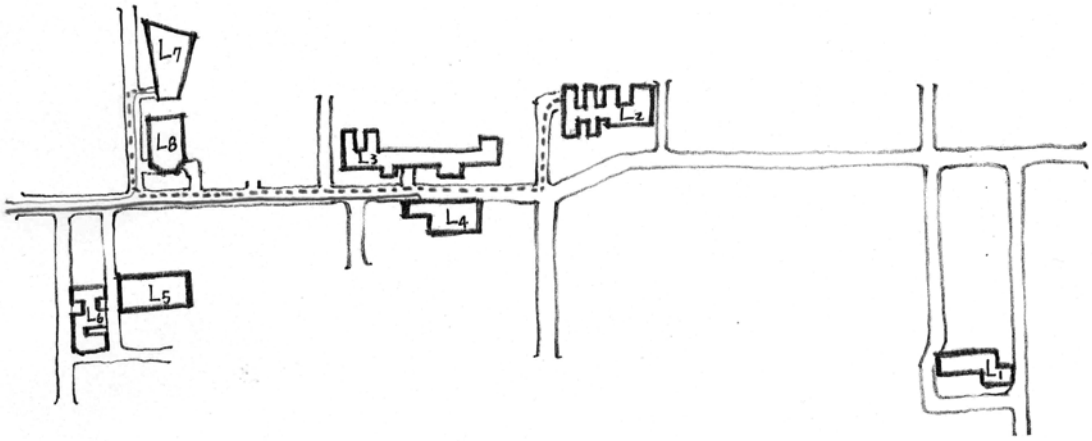

Figure 4.18
Diagram describing movements during time phase 4 (slim line is movement of S1, dotted line is movement of S4, bold line is movement of S 6)

Time Phase 13. 15:45-16:30 7th session
S4 was doing A2 in L4; S6 was also doing A2 in L4. They were doing the same thing in maybe the same place. They might meet each other if they selected the same study room for self-study.

Time Phase 14. 16:30-16:45 Break 6
During this time, S1 was moving from L9 to L9; S4 was moving from L4 to L9. They might meet in L9. However, L9 is very big, so the possibility of their meeting was thus very low.

Time Phase 15. 16:45-17:30 8th session

During this period, S1 was doing A2 in L9 (actually reading at home), S2 was moving from L7 to L9, S4 was in L9 (actually at home). The chance for them to meet was zero.

Appendix 2

Systems of architectural representation

Access graphs were also studied by Hillier & Hanson (1984), and Brown & Johnson (1985), it was identified as 'justified access graphs' to study the 'depth' of space sequence in buildings and urban blocks.

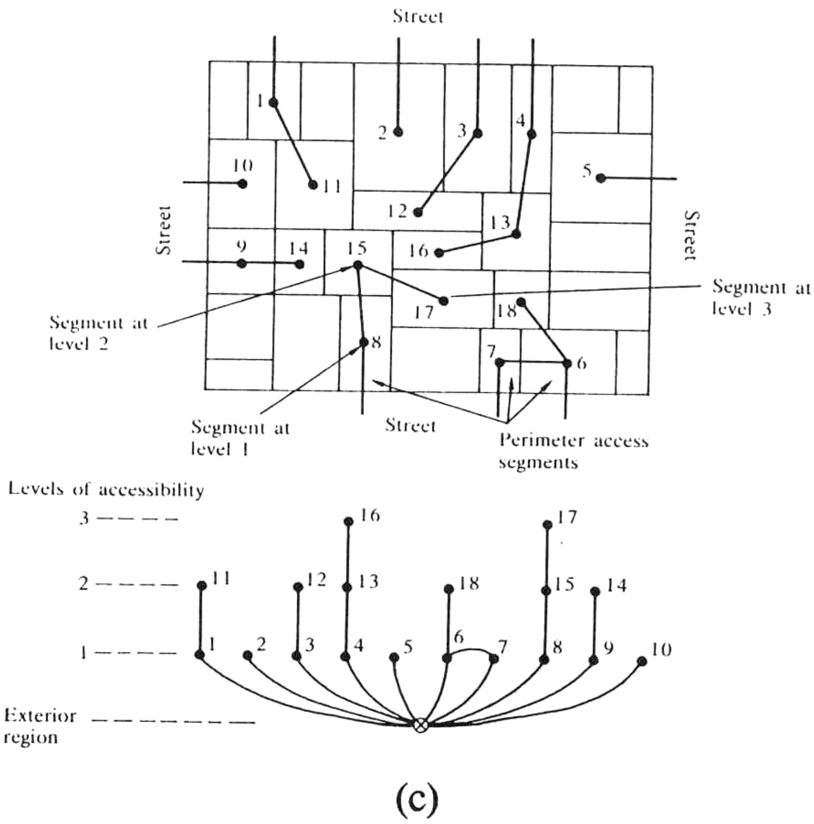

Figure 1: 'Justified access graphs' to study the 'depth' of space sequence (source: Brown & Johnson, 1985)

Hillier argues that built form and spatial organization have subsequent social consequences; misunderstanding nature of the relation between spatial organization and social life is the chief obstacle to better design. He inquiries how and why different forms of social reproduction require and find an embodiment in a different type of spatial order. His theory is helpful to understand the depth of the space sequences or even the social logics behind them, but it is still not enough to understand the interaction of diverse researchers inside the building.

Hillier also uses Y y X x system to symbolize the space sequence from exterior to interior. The carrier space is represented by Y, the relation of containing by o, and the property of being a finite and continuous region of space by 〔〕 (allowing us to make some further description of the object within the brackets if we wish). The left-right formula Y o 〔 〕 express the proposition that a carrier space contains an object (Hillier & Hanson,1984). Once the space system is represented it can be analyzed as a system of syntactic relations. We then can transcribe the system of axial or convex spaces as a graph; that is as a representation in which small circles represent the spaces, and lines joining them represent their relations. (Hillier & Hanson,1984). These relations are summarized as symmetrical, asymmetrical, distributed, and nondistributed.

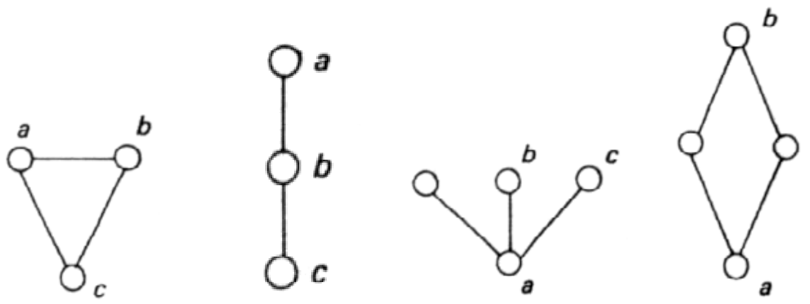

Figure 2: Different spatial relationship: symmetrical; asymmetrical; distributed; nondistributed (source: Hillier & Hanson, 1984)

These basic representational and relational concepts are enough to permit the quantitative analysis of different spatial patterns. These basic concepts can be used to build a general interpretative framework for urban space structures or building complex. Gamma-analysis method is also employed by Hillier, which is generally interpreted for permeability. The basic dimensions of the model can be used to build a technique for the representation and analysis of permeability structures considered as gamma maps. The first stage is a representational device called justified gamma map. Second, the relations of labels to syntax of space can be considered.

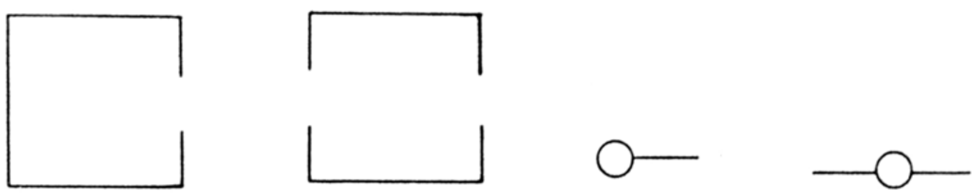

Figure 3: First step to represent space sequences (source: Hillier & Hanson, 1984)

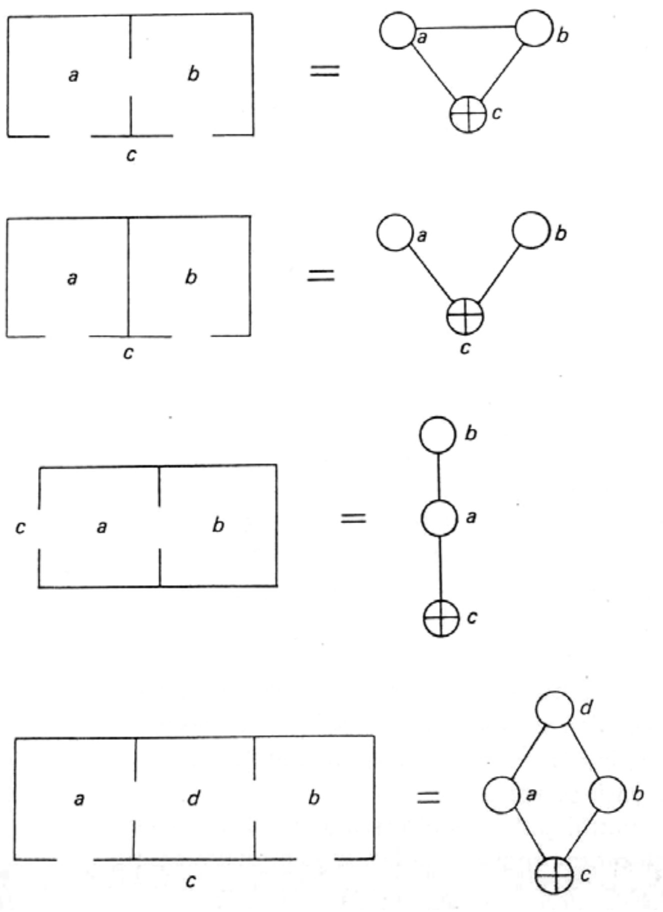

Figure 4: Second step to represent space sequences (source: Hillier & Hanson, 1984)

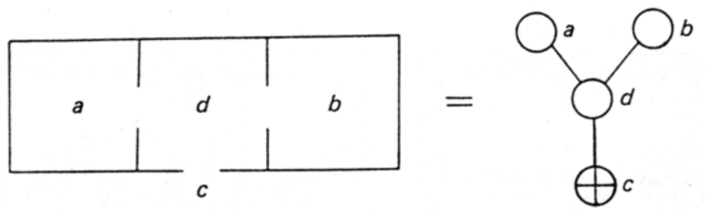

Figure 5: Building and their genotypes (source: Hillier & Hanson, 1984)

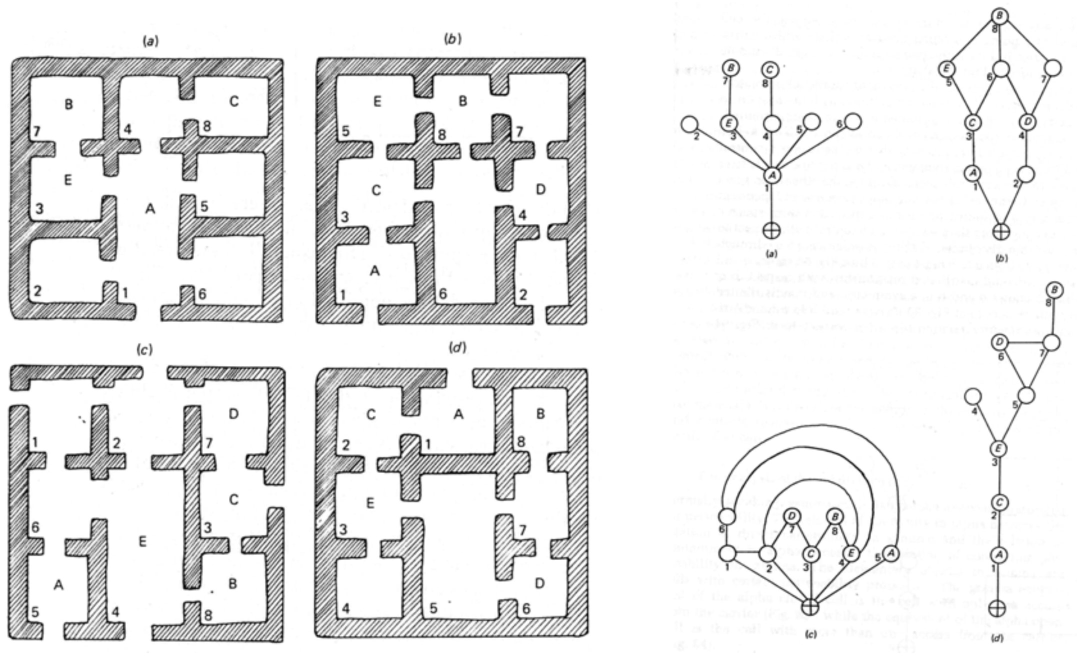

Figure 6: An example to represent spatial consequence (source: Hillier & Hanson, 1984)

The basic assumption behind Hillier’s system is that spatial organization has subsequent social consequences. As one of the social consequences, potential of interaction of diverse researchers is also decided by the topological structure of spatial organization. Therefore the proposed model shall represent these topological structures of spatial organization in Innovation Facilities, which will decide diversity potential in clusters.

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SAMENVATTING

Samenvatting van het proefschrift: ***Een Instrument voor het Ontwerp van Voorzieningen ten behoeve van de Duurzame Productie van Kennis***

Doelstelling van het onderzoek is de ontwikkeling van een methode om ontwerp en planning van voorzieningen ten behoeve van de duurzame productie van nieuwe kennis te verbeteren. Preciezer geformuleerd, beoogt het onderzoek een methode aan te geven om gebouwcomplexen te concipiëren welke betrekking hebben op de lange-termijn productie van nieuwe kennis. Het instrument is gericht op noodzakelijke ruimtelijke voorwaarden die te maken hebben met deze doelstelling, in het bijzonder met topologische netwerken.

Nu zich verstrekkende ontwikkelingen voordoen in wat wel Kenniseconomie wordt genoemd, met logische gevolgen voor onze samenleving, worden we geconfronteerd met uitdagende ontwerpproblemen. Doorslaggevend lijkt het ontwerp van Duurzame Innovatievoorzieningen die aan deze nieuwe behoeften kunnen voldoen, en die het potentieel van de Nieuwe Omgeving in onze tijd kunnen uitbuiten. Teneinde dit nieuwe vraagstuk op te lossen, is er behoefte aan een nieuw stel ontwerpmethoden, met name in de vorm van een ontwerpinstrument.

Het concept Duurzame Ontwikkeling van de economie en van onze omgeving wordt toegepast op de productie van nieuwe kennis. Meer algemeen kan het voornaamste kenmerk van 'Duurzame Ontwikkeling' geformuleerd worden als proces van middels aanpassing bevorderde groei van, tenminste het behoud van de output in een veranderende omgeving.

Een doorslaggevende voorwaarde van een dergelijke aanpassing is diversiteit van kennis onder de mensen die in zogenoemde clusters interacteren. Er bestaan twee mogelijkheden om dergelijke clusters met een hoge mate van diversiteit tot stand te brengen: 1) met behulp van 'virtuele' middelen en 2) middels face-to-face interactie in werkelijke bestaande plekken. Beide hebben hun eigen waarde. De voorzieningen voor de productie van nieuwe kennis moeten dus de voordelen van zowel virtuele, als fysieke middelen combineren. Het in bepaalde situaties te zwaar leunen op virtuele middelen kan leiden tot 'Cyberbalkanisering'. Daarom concentreert dit onderzoek zich op het bevorderen van interactie in werkelijk bestaande plekken in de gebouwde omgeving.

Voor het meten van diversiteit in clusters worden drie stappen overwogen:
1. Vaststellen van clusterlocaties in innovatievoorzieningen;
2. Herkenning van gebruikers, die in dergelijke clusterlocaties interacteren;
3. Het meten van de diversiteit van de actoren die in dergelijke clusters interacteren.

Om tot een beter begrip te komen van de concepten van diversiteit en clustervorming, in samenhang met de fysiek-ruimtelijke organisatie van een voorziening, werd als case study de campus van de TU Delft gekozen. Het onderzoek toont aan dat de kans op fysieke interactie tussen kennis-actoren in clusters met een gevarieerde academische achtergrond klein is. Dit noopt ons tot nadenken over de voorwaarden die deze kans kunnen vergroten.

Ons onderzoek houdt zich vooral bezig met de noodzakelijke voorwaarden van clustervorming met een hoge mate van diversiteit in voorzieningen voor kennisproductie. Deze condities worden gerepresenteerd in termen van topologische netwerken, die in de eerste plaats bestaan uit knooppunten welke plekken voor potentiële ontmoetingen voorstellen; in de tweede plaats uit verbindingen tussen deze knooppunten, die de toegankelijkheid van zulke plekken weergeven. We hanteren voor deze netwerken de term Archigraaf.

Teneinde na te gaan hoe zo'n instrument kan worden opgezet nemen we voor de constructie van het ontwerpinstrument drie voorbeelden van toepassingen onder de loep. Voor wat betreft de programma's in drie verschillende situaties illustreren drie voorbeelden hoe de diversiteit van, in clusters interacterende groepen kan worden vergeleken: situaties met een afwijkende netwerkstructuur en een overeenkomstige bestemming; situaties met een verschillende bestemming, maar met een zelfde netwerkstructuur; situaties met zowel een verschillende bestemming, als een afwijkende netwerkstructuur.

Teneinde het instrument te toetsen, worden twee ontwerp-opties ontleend aan een andere case study van een echte ontwerpcompetitie. We vergelijken de 'diversiteitindex' van programma's waarin het ontwerpinstrument wordt gehanteerd. Op grond van de case study worden mogelijke wijzigingen van het instrument voorgesteld.

Ons uitgangspunt vormden de methodologieën voor de ontwikkeling van ontwerpinstrumenten die werden ontwikkeld door het Design Knowledge Systems Research Center (DKS). In dit verband is dit onderzoek voor wat betreft de volgende punten innovatief:

1. De overdracht van concepten en technieken uit de vakgebieden economie, regionaal onderzoek, de studie van omgevingsduurzaamheid en sociologie, naar het terrein van het ruimtelijk ontwerp op de schaal van het gebouwcomplex;
2. De ontwikkeling van een model dat de ruimtelijke kenmerken die face-to-face groepsinteractie in de gebouwde omgeving beperken;
3. De ontwikkeling van een ontwerpinstrument dat behulpzaam kan zijn bij het evalueren en optimaliseren van de potentiële diversiteit van interacterende groepen in bouwcomplexen.

Het hier voorgestelde ontwerpinstrument is niet bedoeld voor gebruik als deterministische ontwerpmachine, maar als hulpmiddel voor beter begrip van de vergelijking van alternatieve bouwplannen. Hierbij wordt het topologisch netwerk beschouwd als een noodzakelijke voorwaarde voor de verbetering van fysieke interactie tussen diverse actoren.

Sleutelwoorden:
Duurzame Innovatievoorzieningen; Noodzakelijke Ontwerpvoorwaarden; Diversiteit in Clusters; Archigraaf; Ontwerpmethodologie; Ontwikkeling van Ontwerpinstrumenten

About the Author

Jun WU was born on September 15, 1970, in Wuhan, China. In July 1993, he completed his Bachelor of Engineering degree at the School of Architecture, Huazhong University of Science and Technology. After receiving his Master of Architecture degree at the School of Architecture and Urban Planning, Chongqing Jianzhu University in July 1996, he started teaching in the school of Architecture in Huazhong University of Science and Technology. At the end of 2000, he moved to the Netherlands to work for his doctorate degree at the Design Knowledge System Research Center (DKS) at the Faculty of Architecture (Bouwkunde), Delft University of Technology (TUD), in the Netherlands.

In 1992 when he was a student at university, he won the First Prize of the 29^{th} International design Competition in Landscape Architecture organized by IFLA (International Federation of Landscape Architects). Two years later he was invited to the Headquarters of UNESCO in Paris to be awarded the UNESCO Prize in Landscape Architecture. During his teaching and research in China, he was involved in several important design projects varying from architectural design to urban planning. He has published a number of papers about his research, and in 2000, his book *Office Architecture* was published in China.

In 2001, the Dutch Ministry of Education, Culture and Science granted him a 'Huygens' scholarship. While working in DKS, Bouwkunde, TUD, he has been involved in some teaching and lecturing in the faculty. He has also participated in several Chinese Projects through some Dutch design offices. In 2003 he was invited to participate as a Senior Consultant of the 'Urban China 2020' project in the Dutch Dynamic Urban Foundation and gave a lecture in BNSP (Dutch Professional Organization of Urban Designers and Planners) in Amsterdam, the Netherlands.