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A Performance Based Approach To Set Up A Design Frame Work : The Case of University Laboratory Facilities in Algeria

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Salah Eddine El Ayoubi KRADA.

To my Mum & Dad with love

ABSTRACT

A PERFORMANCE BASED APPROACH TO SET UP A DESIGN FRAME WORK : THE CASE OF UNIVERSITY LABORATORIES FACILITIES IN ALGERIA

By
Salah Eddine El Ayoubi KRADA

The establishment of adequate terms of reference has become an essential requisite for the provision of future Algerian university laboratory facilities. The association of a number of factors, including i) a continuous growth is student numbers, ii) the paucity and inadequacy of design guidance in current use, iii) the lack of authorities in the field of university and laboratory building design and iv) the scarcity of material resources, has made acute the problems faced by those involved in the design of these buildings. To enhance the quality of design guidance and ultimately to achieve a quality laboratory environment two major tasks were attempted in this study:

i. To identify and examine the extent of relevance of International university laboratory facilities related design concepts for similar Algerian ones.
ii. To suggest suitable design related concepts that could possibly govern future Algerian university laboratories facilities design.
iii. To assess the relevance of performance based methods to enhance quality of design of university laboratory facilities.
iv. To assess, by means of a case study, the relevance of yardsticks and benchmarks in current use in measuring the state of fit in the interface user/space of the available building stock.

Examination of the specialised literature indicated that laboratory facility design is controlled by design pre-requisites. These were identified as those claimed as functional or physical attributes and those as environmental ones. The surveyed literature also brought to notice the complexity of having to design for the needs for immediate use and yet being able to meet responsively the occurrence of future change and growth in the laboratory's activity. Furthermore, as the rate of sociotechnic change accelerates, the construction of predetermined unchangeable buildings become more and more questionable. The post occupancy evaluation specialized discourse is thoroughly scrutinized in order to help setting up a sound and yet necessary feedback with regard to laboratory facility. Last but not least, the concept of Sustainability is highlighted as an inescapable design objective.

The study showed that if a dynamic learning space is to be provided, the inclusion of a potential for changes and uncertainty, as intrinsic parameters in the process of laboratory facility design, is of a primary importance. These potential designs, approaches to mitigate the effects of change upon laboratory buildings were identified. These were flexibility, long-life loose-fit and scrapping. While the first two approaches were found to have some feasibility the third one remained a bold claim, but an impractical one.

The study achieved, to a large extent, the aims set out above and culminated with some relevant recommendations to help bridging the knowledge gap in laboratory facility design in Algeria.

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> … ***Lord, grant me the capacity to be grateful for Thy favour which Thou hast bestowed upon me and upon my parents and to act righteously so as to win Thy pleasure and to admit me by Thy mercy, among Thy righteous servants.***
>
> **Koran, Chp.5, Verse 3.**

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TABLE OF CONTENTS

Page No.

ABSTRACT……………………………………………………………………………..i
ACKNOWLEDGEMENTS………………………………………………………………..ii
CONTENTS...iii
LIST OF TABLES ……………………………………………… ………… ……………xi
LIST OF FIGURES …………………………………………………………………………xii
LIST OF ACRONYMS…………………………………………………………………...xiv
LIST OF APPENDICES ……………………………………………...……. …………… xv
GENERAL INTRODUCTION ……………………..…………………………………………4

CHAPTER ONE:
DEVELOPMENT OF UNIVERSITY BULDINGS IN ALGERIA AND THE RESEARCHING SCOPE

1.1. Introduction ……………………………………………. 12
1.2. Chronological Evolution of The Algerian Higher Education System ……………………..…… 12
1.2.2. The Post Colonial Period: 1962-1971 ………………… 13
1.2.2.1. The Organisation of the Traditional University ………………..……… 16
1.2.3. The 1972-1984 Era and the Advent of Higher Education Reform …………………………..……… 16
1.2.3.1. Foundation of Higher Education ………………………………… 17
1.2.3.2. Algerian Universities With the Advent of Reform ……………………………………….………….. 17
1.2.3.2.1. The Integration of Training Programmes ………………………………………...…………. 18
1.2.3.2.2. The Integration of Structures ………………………..………… 18
1.3. Physical Development …………………………………………… 18
1.3.1. The Emergency Programme …………………………...……… 19
1.3.2. The carte Universitaire ……………………………………..……. 19
1.4. New Trends in the Provision of Universities ………………………………………..……………. 19
1.5. Education System ……………………………………..…………. 20
1.6. Design Guidance ………………………………………………..…. 21
1.7. Identification of Problems ……………….……………………… 22
1.7.1. The Difficulty of Assessing Demand Adequately ……………………………...……… 23
1.7.2. The Nature of Design Guidance ………………………….……… 23
1.7.3. Lack of Expertise …………………………………………….…….. 24
1.7.4. Inappropriateness of Evaluation And Documented Studies ……………………………….…….. 24
1.8. The Scope of Research ……………………………….…………. .25
1.9. Summary …………………………………………………… 26
1.10. References ……………………………………………………….. 29

CHAPTER TWO:
CURRENT DEVELOPMENTS IN THE DESIGN OF LABORATORY FACILITY

1 Introduction 32
1.1. The Laboratory Precinct As "Social Buildings" 32
1.2. Meeting Places 33
1.3. Team-Based Labs 33
1.4. "Open" Versus "Closed" Labs 34
2. Flexibility 35
2.1. Flexible Engineering Systems 35
2.2. Equipment Zones 36
2.3. Generic Labs 37
2.4 .Mobile Casework 37
2.5. Using the Full Volume of the Lab Space 38
2.6. Overhead Service Carriers 39
3. Wet and Dry Labs 40
4. Design for the Computer 40
5. Virtual Labs 41
6. Sustainability 42
7. Science Parks 44
8 References **44**

CHAPTER THREE:
DESIGN REQUIREMENTS OF UNIVERSITY LABORATORY FACILITY

PART ONE

3.1. Introduction 45
3.2. The Rise of University Laboratories 47
3.3. Laboratory Taxonomy 48
3.3.1. Laboratories Classified According to Activity. 48
3.3.1.1. Teaching Activity. 48
3.3.1.2. Research Activity. 49
3.3.1.3. Routine Activity. 49
3.3.1.4. Wet Laboratories 50
3.3.1.5. Dry Laboratories 50
3.4. Planning Considerations and the Design of Laboratory facility 51
3.4.1. Location. 51
3.4.2. Physical Attributes of Laboratory Space. 52
3.4.2.1. Space Standards. 52
3.4.2.2. Laboratory Height. 52
3.4.2.3. The Module. 53
3.4.3. Furniture and Equipment. 53
3.4.3.1. The Bench. 54
3.4.3.2. Disposal Services. 56
3.4.3.3. Fume Cupboards. 56
3.4.4. Services and Structure. 57
3.4.4.1. Services. 57

3.4.4.2. The Structure. 58
3.4.5. Environmental Attributes of Laboratory Space. 58
3.4.5.1. Noise Control and Acoustics. 59
3.4.5.2. Day lighting Factor. 60
3.4.5.3. Fire Safety and Hazards. 61
3.4.5.4. Ventilation. 62
3.5. References Part One 64

PART TWO

4. Physical Hazards 70
5. Casework: 70
6. Chemical Fume Hoods 70
7. Placement of Biological Safety Cabinets (BSCs) in Lab Module: 70
8. Equipment: 71
8.1. Autoclaves: 71
8.2. Gas Cylinders: 71
8.3. Flammable and Waste Storage: 71
9. Architectural Finishes and Materials 72
9.1 Floor and Base Materials: 72
10.2 Walls: 72
10.3 Ceilings: 72
10.4 Windows and Window Treatment: 72
10.5 Doors: 73
10.6 Door Hardware: 73
11 Structural 73
11.1 Module/Bay Size 73
11.2 Floor Slab Depressions: 74
12 Heating, Ventilation, and Air Conditioning (HVAC) 74
12.1 Lighting Loads: 74
12.2 Occupancy Loads: 74
12.3 Ventilation Loads: 75
12.4. Laboratory Equipment Cooling Loads 75
12.5. Normal Power 75
12.6. Lighting: 76
13. Biological Safety 76
14. Radiation Safety 77
14.1 Radioactive Waste Storage On-Campus Buildings: 77
.15. Summary. 77
16 .References PART TWO 79

CHAPTER FOUR:
GROWTH AND CHANGE AND THE PHENOMENA
OF OBSOLESCENCE IN BUILDINGS

1. Introduction 82
2. Definition of Obsolescence 83
3. Causes of Obsolescence 83
3.1. Functional factors, 84

3.2. Economic factors, 84
3.3. Technological factors 84
3.4. Social, legal, political, or cultural factors, 84
4. Strategies to Mitigate Obsolescence 85
4.1 Planning and Programming 85
4.2. Predesign Scrutiny 85
4.3 Actions in Design 86
4.3.1 Design Guidance 86
4.3.2. Making Flexibility a Design Goal 87
4.3.3. Adopting Details That Enhance Flexibility 87
4.3.3.1 Unconstrained Interior Space. 87
4.3.3.2 Accessible Service Areas. 87
4.3.3.3 Modularity. 88
4.3.3.4 Shell Space 88
4.4. Actions In Maintenance 88
4.5 Post occupancy Evaluation in Facility Management 89
4.6. Adapting for Reuse 89
5. Références 91

CHAPTER FIVE:
FLEXIBILITY A KEY ISSUE IN PLANNING FOR CHANGE IN LABORATORY DESIGN

1. Introduction. 93
2. Definition and Concepts. 94
3. The Problem of Change. 95
3.1. The Growth of Student Numbers. 97
3.2. Change in Technology. 97
3.3. Change in the Curricula .99
3.4. Change in the Activity Size. 100
4. Design Strategies for Coping with Change. 101
4.1. Flexibility. 102
4.2. The Long-Life Loose-Fit Concept. 103
4.2.1. Over-Provision. 104
4.2.2. Neutrality. 104
4.3. Scrapping. 105
5. Conclusion 106
6. References: 108

CHAPITRE SIX:
ACHIEVING SUSTAINABILITY FOR LABORATORY FACILITY

PART ONE

1. Laboratory type According to Activity 114
1.1. Chemistry Laboratories 114
1.2 Biosciences Laboratories 114
1.3 Physical Sciences Laboratories 115
2. Design Flexibility 115

2.1. Energy Efficiency and Design Flexibility 115
2.2 Adjustability 115
2.3 Expandability 116
2.4 Operational classifications 116
3. Understand Barriers 116
4. Conflicts among flexibility types 117
4.1 Physical Conflicts 117
4.2 Safety Conflicts 117
5. Flexibility and planning 117
6. Laboratory Adjacency 118
6.1. Energy Efficiency and Laboratory Adjacency 118
6.2. Support activity integration 118
7. Environmental Design Attributes 119
7.1 Life-cycle Cost (LCC) Analysis 119
7.2. LCC factors 119
7.3. LCC design factors 120
7.3.1. LCC and Adequate Space 120
7.3.2 LCC techniques 120
3.3. 7LCC Economic Factors 121
7.3.4. VAV Systems 121
7.3.5. LCC Performance Factors 122
8 Diversity Analysis 122
8.1. Energy Efficiency and Diversity 122
9. Modular Design 123
9.1. Energy Efficiency and Modular Design 123
9.2. Laboratory Modules 123
9.3. Fume Hoods and Laboratory Modules 124
9.4. Cleanroom Modules 124
10. Utility Service Spaces 125
11. Retrofits 130
12. Performance Measurement 130
13. REFERENCES 131

PART TWO
PART 2:
EVIRONMENTAL ISSUES 134

1. Introduction 134
2.. Architectural Considerations 135
2.1. Overhangs 135
2.2 Glazing 135
2.3 Roofs and Walls 136
3. Engineering Considerations 136
3.1.Civil Engineering 136
3.2.Mechanical, Plumbing, and Water Conservation Strategies 136
3.3.Sustainable Lighting Design 138
3.3.1.Daylighting 138
.3.2. Lighting Controls 139
4.Other Sustainability Issues 139

5. Conclusion 140
6. References 143

PART 3
ACHIEVING THE BUILDING ENVELOPPE SUSTAINABILITY

1. Introduction 144
2. Description 145
2.1. Optimize Site Potentia l45
2.2. Minimize Energy Consumption 145
2.*3.Protect and Conserve Water 146*
2.4. Use Environmentally Preferred Products 146
3. Emerging Issues 146
3.1.Balancing Security/Safety and Sustainability Objectives 146
3.2.Integrated Design 147
4. References 148

CHAPTER SEVEN
POST OCCUPANCY EVALUATION A PERFORMANCE BASED APPROACH: CONCEPTS AND TOOLS

1. Background & Literature Search 150
2. Post-Occupancy Evaluation A Chronological Glance 159
3. What is Post Occupancy Evaluation? 151
4 Definitions 153
5. Theory 154
6. The Nordic Model as a Point of Departure 154
7. Process 155
8 Planning the POE 156
8.1. Reconnaissance and Feasibility 156
8.2. Resource Planning 156
8.3. Research Planning 156
8.4. POE STEPS 157
9. Phases of POE s 157
9. 1.Techniques of Data Collection in POEs 158
10. POE Tools 158
10.1. Practical Techniques for Undertaking POE: 158
10.2 Data Collection and Analysis 159
11. CONCLUSION 160
12. REFERENCES 161

CHAPTER EIGHT:
CASE STUDY.

8.1. Introduction. 166
8.2. The Methodology 167

8.2.1. Choice of Sample. 167
8.2.2. Observation 168
8.2.3. Interviews. 168
8.2.3.1. Interviews With Heads of Schools. 169
8.2.3.2. Interviews With the Users. 169
8.2.3.4. Measurements of Plans. 169
8.3. Background to Constantine Mantouri Campus. 169
8.4. Description of the Sample 171
8.5. Assessment of the Planning aspects. 172
8.5.1. Location. 172
8.5.2. Space Standards. 173
8.5.2.1. Usable Area Per Student. 173
8.5.2.2. The Height of Laboratories 175
88.6. Assessment of Furniture and Equipment in the Laboratories. 175
8.6.1. Furniture. 175
8.6.1.1. The Bench Requirements 175
. 8.6.1.1.1. The Width of the Bench. 176
8...6.1.1.2. The Height of the Bench. 176
8.5.1.1.3. Gangways. 176
8.6.2. Equipment. 178
8.6.2.1. Storage. 178
8.6.2.2. Fume Cupboards. 178
8.6.2.3. Other Elements of Equipment. 178
8.6.3. The Services. 178
8.6.4. The Structure. 179
8.6.5. Environmental Assessment. 179
8.6.6. Assessment of the Potential for Change in the Initial Design. 183
8.7. Summary 183
8.7.1 Future Directions 184
8.7.2. Physical Influences 184
8.7.3 Behavioural Influences 185
9. References. 186

CHAPTER NINE:
CRITERIA AFFECTING THE TRANSFER OF LABORATORY FACILITIES DESIGN REQUIREMENTS TO THE ALGERIAN CONTEXT

1. Introduction. 187
2. The Fallacy of the Average Man Concept. 187
2.1. Human Measurement Constraints. 188
2.2. Environment Constraints. 189
2.2.1. Noise. 189
2.2.2. Thermal Comfort. 190
2.2.3 Lighting Constraints . 191
2.2.4. Anthropometric comparison 191
3. Geo-Climatic Constraints. 194
4. Availability of Resources. 196
5. Organisational Aspects. 198

6. Summary. 199
7 References. 200

CHAPTER TEN:
CONCLUSION AND RECOMMENDATIONS

1. Introduction. 202
2. Recapitulation: Aims, Research Problem and Methodology. 202
3. Recommendations. 204
3.1. Organisational Aspects. 204
3.2. Evaluation and Feedback Data. 205
3.3. Availability of Resources. 205
4. Planning and Design Recommendations 205
4.1. Space Standards. 206
4. 2. Services and structure. 206
4. 3. Flexibility. 206
5. Further Research. 206
6. General Conclusion. 2O7

LIST OF TABLES

Page No
Table 1.2.1. (i):Hierarchical Structure of Education During the Colonial Era (1830- 1962) 12
Table 1.2.1. (ii):Proportion of Algerian Students in Higher Education During the Colonial Era. 13
Table 1.2.2. (I): Growth in the Number of University Students During the Decade of 1962-1972 13
Table 1.2.2.(ii):Proportion of Architectural Firms Practising in Algeria in 1969. 15
Table 4: Forecast Proportion of Students in the Fields of Science and Technology 19
Table 3.4.2.2: Usable Area per Student According to their Year of Course. 51
Table 3.4.3.1. (I): Bench Lengths According to Scientific Discipline 53

Table 3.4.3.1. (I): Bench Lengths According to Scientific Discipline 54
Table 3.4.3.1. (IV): Bench Spacing According to Conditions of Use 54
Table .4.1Lighting Loads 72
Table .4.2 Occupancy Loads 73
Table .4.3 Ventilation Loads 73
Table 4.5 Normal Power Load Figures 74
Table 5 sustainable design criteria 139
Table 8.5.2.1a:
Comparison of the Recommended Usable Areas per Student With those currently in Use in the Laboratories. 171

Table 8.5.2.1b:
Results of the Physical Survey of the Laboratories. 171
Table 8.5.2.3.
Comparison of the Grid Dimensions With Those In Current Use in Laboratories. 172
Table 8.6.5.Environmental Survey of the Laboratories 178
Table 8.6.1.1.:
Comparison of Recommended Bench Dimensions With Those in Current Use in the Laboratories. 173

Table 8.6.1.2.
Results of the Furniture and Services Surveys of Laboratories Visited. 174
Table 9.2.2.2:
Comparison between British and Algerian Thermal Comfort Zones. 186

LIST OF FIGURES

FIGURE A: *Laboratory classroom set up for group laboratory work And teacher demonstration or mini-lecture.* *10*
FIGURE B: Laboratory classroom set up for small-group investigations At central benches and individual activities at side benches. *10*
Figure C: Evolution des Effectifs Durant la Décade 96/97 à 2006/2007 *30*
Figure D: Capacités Pédagogiques par Région *30*
Figure 3A What are the most important criteria in building a laboratory *94*
Figure 3B How do you want to change your Research and developpement capabilities *95*
Figure 9.4. Clean room Modules *122*
Figure 10 A. Utility Service Spaces *125*
Figure 10B. Suspended Ceiling Layout *126*
Figure : The EPA Campus at Research Triangle Park, North Carolina 131
Figure: Sun Control and Shading Devices. 132
Figure 6: Systematic Evaluation and Assessment of Building Environmental Performance *141*
Figure 7. Air Leakage through a Building Enclosure 142
Figure 8: The Nordic Model as a Point of Departure 152
Fig 9: View of the SCIENCE BLOC lit from above 163
Fig 10: Views of the Mentouri Constantine Campus 167
Figure 11.A: Schematic Overall Plan of the Campus 170
Figure 11 B: Main Entrance to Science BLOC 170
Figure 11 C: View of the SCIENCE BLOC lit from above 170
Figure 8.6.2.1.*Storage racks of Chemistry Laboratories Visited.* *175*
Figure 8.6.2.2. *Fume Hoods of Chemistry Laboratories Visited* *176*
Figure 8.6.2.3.Heavily serviced electronic power and supplies

LIST OF ACRONYMS

B.R.E	British Research Establisheent
C.N.R.S.	Centre National de la Recherche Scientifique.
D.E.S.	Department of Education and Science.
L.E.A.	Local Education Authority.
LAB 21st	Laboratory of Twenty First century (UK & Us Branches)
L.E.E.D	Leading Environmental and Energy Design
L.I.U.	Laboratoires Investigation Unit.
M.E.S.R.S.	Ministère de l’Enseignement Supérieur Et de la Recherche Scientifique
N.A.B.	National Advisory Body for Public Sector Higher Education.
N.I.H	National Institute of Health
P.C.F.C.	Polytechnic and Colleges Funding Council.
U.F.C.	University Funding Committee.
U.G.C.	University Grants Committee.

APPENDICES

APPENDIX A

Design Guidance (Programme de Realisation)
For Algerian university buildings (4000 students) 208

APPENDIX B

B1. Materials Suitability for Laboratory Purposes.212
B2: Materials for Draining Boards and Suitability for Laboratory Purposes.213
B3: Level of Provision of Services for Specific Scientific Discipline.214
B4 Units of Measure214

APPENDIX C

Recordings Sheets 218

APPENDIX D

Questionnaire 222

BIBLIOGRAPHY 232

CHAPTER ONE:
DEVELOPMENT OF UNIVERSITY BUILDINGS IN ALGERIA AND THE RESEARCH SCOPE

1.1. Introduction.

The first part of this introduction chapter seeks to outline the major developments which have occurred in Algerian higher education in recent years and to provide a background to some of the problems peculiar to it. The second part aims to identify some of the problems encountered when designing university buildings and to define the research problem to be tackled in this investigation.

In order to achieve a better understanding of the situation in higher education in Algeria and the need for adequate and explicit design guidance, it is necessary to profile chronologically the evolution of the country's higher education system. Thereafter, this study seeks to assess building performance with regard to university science laboratories in Algeria. Its chief aims are:

v. To identify and examine the extent of relevance of International university science teaching laboratories related design concepts for similar Algerian ones.
vi. To suggest suitable design related concepts that could possibly govern future Algerian university science teaching laboratory design.
vii. To assess the relevance of performance based methods to enhance quality of design of university science laboratories.
viii. To assess, by means of a case study, the relevance of yardsticks in current use in measuring the state of fit in the interface user/space of the available building stock.

The provision of university buildings has always been a major interest of the central government. Since the early days of independence, Algeria has faced an immense growth of student numbers, increasing from 5,000 on the eve of the independence (1962) to over 1.000.000 at present. Further more, the paucity and inadequacy of design guidance, the lack of feedback studies and authorities in the planning and design of university buildings and laboratory design in combination with the scarcity of material resources strained and made acute the problems involved in the provision and design of these buildings.

To help ease the situation, Algeria turned to foreign aids in terms of finance as well as planning and architectural design expertise. The type of architecture brought in was of an international style showing little respect to a number of constraints that of: technology know-how, cultural variability, geo-climatic conditions, availability of resources and organisational aspects.

A vast expenditure is now being allocated to university buildings in Algeria, regardless of what have been achieved so far, over the last thirteen years, and no appraisals or assessments studies have been made available to those who are involved in designing higher education laboratory facilities.

At present, there does seem to exist an exceptional opportunity for improvement in almost all spheres connected with higher education facilities. However, the subject of university buildings is a wide one and it would be virtually impossible within the scope of this study to encompass all, or even a large part of the various architectural facets involved in the design of these buildings. It is therefore reasonable to limit the scope to a particular space within the context of higher education facilities.

The argument advocating a study of higher education laboratory facilities is threefold. First, the ultimate priority given by central government to set up an infrastructure in science and technology that is educationally desirable and necessary for the economy. Second, there exists a chronic deficiency of both experts and documented studies in the field in Algeria. Finally, the resurgence of interest world-wide around the subject of science laboratory planning and design, to improve health, safety and efficiency standards, brought to light the complexity of having to design for an immediate use and yet to incorporate a potential for flexibility and adaptability in the design process of science laboratories buildings.

To achieve this, international experience was considered relevant due to two main reasons. First, the availability of resources in conjunction with the time constraint led to a pragmatic approach. It was felt unwise to extrapolate an array of theoretical design expedients and related concepts to Algeria while the extent of their relevance has yet to be established. This procedure could only be possible if a case study is carried out so as to test the relevance of these design expedients. Second, the availability of a bulk of relevant literature and experts in the fields of planning and design of university science laboratories design made stronger the case for studying international expertise and experience.

Laboratory facilities are complex, technically sophisticated, and mechanically intensive structures that are expensive to build and to maintain, and therefore the design, construction, and renovation of such facilities is a major challenge for all involved. Hundreds of decisions must be made before and during renovation or new construction. These decisions will determine how successfully the facility will function when completed and how successfully it can be maintained once put into service. Yet many of these decisions must be made by users and administrators whose knowledge of basic and more laboratory specific design, construction, and renovation is minimal at the start of the project and must be rapidly increased.

Laboratory design has been the subject of extensive expertise and particularly in the Anglo-Saxon part of the world. This to mention that most authorative outcomes were derived from works of the Labs 21st ((both US an UK branches 1999/2007), LIU (laboratories investigating unit 1970/ 1985), the NRC (national research council 1930/1951/1960) the NIH (national institute of health 1999) and the R&D (2000/2008)

These works, however, are addressed to the professional design community, whose members are already familiar with general design and construction issues and processes. What has been lacking is both basic and laboratory-oriented information addressed to the user community the scientists and administrators who contract with the architects, laboratory designers, and engineers who will design the facility and the construction personnel who will build it. Questions about the value science laboratories stem in part from a lack of clarity about what exactly constitutes a “laboratory” and what its science learning goals might be. For example, “laboratory” may refer to a room equipped with benches and student workstations, or it may refer to various types of indoor or outdoor science activities. A successful laboratory facility is defined as one that provides effective flexibility, safety for laboratory workers, compatible with the surrounding environment, has the support of the neighbouring community and governmental agencies, and can be constructed in a cost-effective manner. This research thesis will try to cover many relayed aspects with respect to laboratory facility design.

Most people in this country lack the basic understanding of science that they need to make informed decisions about the many scientific issues affecting their lives. Neither this basic understanding—often referred to as scientific literacy—nor an appreciation for how science has shaped the society nor culture is being cultivated during the school years. Yet policy makers, scientists, and educators agree that graduates today, more than ever, need a acute understanding of science and technology in order to function effectively in an increasingly complex, technological society. Increasing this understanding will require major reforms in science educations as and significant laboratory facility design.

This lack of clarity in design guidance together with inefficient available expertise or scarce feedback about laboratories has jeopardised scientific levels and contributed to slowing researchers on their outcomes. In addition, mechanisms for sharing the results of the research that is available—both within the research community and with the larger higher education community—are so weak that progress toward more effective laboratory learning experiences is impeded. More over the rapid developments in science, technology, and cognitive research have made the traditional definition of science laboratories—only as rooms where students use special equipment to carry out well-defined procedures—obsolete To frame the scope of the forgoing study: ***Gaps in capturing the knowledge and basic understanding of design, evaluation and sustainability related aspects of laboratory facilities are major arguments that erect the backbone of the present thesis.***

Challenges of providing appropriate physical space requirements for laboratory facility, environmental attributes are also so acute. We consider all complexities argued to be the back bone in the design of laboratory facilities. We review relevant literature with regard to laboratory facilities including physical spaces requirements, equipment, supplies, safety, liability, benchmarking, and current patterns of sustainability enforcement. In response to growing enrolments and overcrowdings of older higher education facilities, Ministry of Higher Education and Scientific Research (MHESR) had undergone, since the mid 1990s, an unprecedented wave of construction and enhancements of higher education facilities all across the country from north to south and from west to east. A comprehensive survey conducted by the MHESR in 1999 revealed that many existing facilities buildings were in need of acute and yet urgent building enhancements operations. The survey report concluded that, one-third of the building stock of the nation needed either extensive renovation or reconstruction, while another third had at least one major dysfunctional in relation to the following:

- Sitting and space planning
- Structural flaw, such as a leaky roof.
- Obsolete HVAC (electrical system, or dysfunctional plumbing) (MHESR 1999)
- Serious environmental concerns
- Poor sustainability determinants in the onset design process.
- Design guidance ought to be reformed.

Trend data from delivered by the department of planning and prospective indicated that budget spending nearly doubled over the past decade, increasing from 145 billions DA in

1996 to 285 billions DA in 2005 (MEHSR, 2005). About 60 percent of these expenditures were devoted for new construction while the resting 40 percent was for extensions or renovations to existing buildings. Mr Balamne, head of the department of planning and prospective within the MHESR, argued that almost half of the expenditures committed to newly built facilities were in fact for erecting Laboratory facilities and technology oriented buildings. Ever since independence, there has been little research examining physical laboratory facilities within higher education buildings in Algeria. Further more, during the course of this research we found hard to trace back any systematic national feedback data upon which current higher education laboratory facilities incorporate any of the aspects of flexibility described above. No systematic information was available to help higher education laboratory facilities designers to allow for easy movement from laboratory work to group discussions or lectures and/or to accommodate multiple science disciplines. For example, almost no information was available on the fraction of higher education laboratory facilities that include combined laboratory-classroom space instead of separate laboratory rooms

While the design of particular facilities will vary depending on the local science curriculum, available resources, and building codes, all laboratory facilities should provide space for shared teacher planning, space for preparation of investigations, and secure storage for laboratory supplies as well as space for student activities and teacher demonstrations. In addition, past studies (Novak, 1972; Shepherd, 1974) and current laboratory design experts (Lidsky, 2004) agree that laboratory designs should emphasize flexible use of space (see figures 1.1 (i) &1.1(ii) below) and furnishings to support integration of laboratory experiences with other forms of science instruction Combined laboratory-classrooms can support effective laboratory experiences by providing movable benches and chairs, movable walls, peripheral or central location of facilities, wireless Internet connections and trolleys for computers, fume hoods, or other equipment. These flexible furnishings allow students to move seamlessly from carrying out laboratory activities on the benches to small-group or whole-class discussions that help them make meaning from their activities. Integrated laboratory-classrooms that provide space for long-term student projects or cumulative portfolios support the full range of laboratory experiences, allowing students to experience more of the activities of real scientists. Forward-looking laboratory designs maximize use of natural sunlight and provide easy access to outdoor science facilities. See Figures A and B for examples of laboratory-classrooms with flexible designs. Designing laboratory facilities to accommodate multiple science disciplines could provide both educational and practical benefits. First, because undergraduate science education, like science itself, is becoming more interdisciplinary. Laboratory facilities that could accommodate interdisciplinary investigations would help prepare students for such undergraduate laboratory courses. Second, high students enrol in a wide variety of science courses (MHESR Statistics, 2005). It may be more cost-effective to provide this variety with a few laboratory classrooms that can accommodate multiple disciplines than by constructing discipline-specific laboratory classrooms that remain unused at times. In 1999, two teachers' associations—the National Science Teachers Association and the International Technology Education Association, based US based, —mailed a survey to their members and received about 2,000 responses (Lab Plan, 2004). Among the 900 National Science Teachers Association members who responded, over three-fourths indicated they taught in combined laboratory-classrooms. Among the 1,200 responding International Technology Education Association members, who taught drafting, technology education, and manufacturing courses, just under half taught in a combined laboratory-classroom and one-quarter taught in a combined laboratory–production classroom (Lab Plan, 2004)

Because laboratories require space for student activities, shared teacher planning, teacher demonstrations, student discussions, and safe storage of chemicals, along with specialized furnishings (e.g., sinks, benches) and utilities (e.g., water, gas), they are more expensive to build and maintain than other types of school space. Biehle et al recent work on laboratory facilities indicates that "laboratory space is approximately twice as expensive to build and equip as classroom space." (Biehle et al., 1999, p. 56). According to one architect specializing in educational science laboratories, in 2004, the costs of laboratory space in New England ranged from $180 per square foot for general science and physics to $250 per square foot for chemistry and biology (Lidsky, 2004). At $250 per square foot, these laboratory costs are about 1.7 times more expensive than the costs of new high school space in New England, estimated at $148 per square foot in a recent survey (Abramson, 2004).

Although funds to plan, design, and build a new laboratory facility come from central government, the supplies and equipment needed to use the laboratory space come out of the operating budget. In some cases, there may be enough capital budgets to build a laboratory, but no funds are set aside in the operating budget to provide the equipment and supplies to use the laboratory over subsequent years. The author observed that: It is not uncommon in jurisdictions throughout the country to find people who invest a tremendous amount of money in the fabric and then under fund them historically once they are built. It may be that there is no equipment, or it may be that they buy the equipment once and they don't buy the disposable materials every year in order to use them. There is no consensus as to how one budgets those resources into the foreseeable future.

FIGURE 1.1.(i): ***Laboratory classroom set up for group laboratory work and teacher demonstration or mini-lecture.***

SOURCE: *Lidsky (2004).*

FIGURE 1.1.(ii): ***Laboratory classroom set up for small-group investigations at central benches and individual activities at side benches.***

SOURCE: *Lidsky (2004).*

1.2. Chronological Evolution of the Algerian Higher Education System.

1.2.1. The Colonial Period: 1830-1962.

Before the French landed in 1830, there existed in each Algerian village an average of two schools, evidence that public education was widespread all over the country. (1) Mr. Turin argued that after the French settlement, there was major concern about educational order produced anti-settler beliefs and ideology. (2) Moreover, massive destruction of existing educational buildings (e.g. madras and mosques) took place at the turn of the nineteenth century as a part of the rulers' (colonialists) policy. (3) A new and alien educational system was built up to give French needs priority as can be seen from table 1.2.1. (4)

At the specific level of higher education, the subject of this thesis, opportunities for Algerians were very restricted. (5) The number of Algerian university students reached its peak on the eve of national independence when it rose to 600 out of a total student population of 5,000. (6) These statistics, it is argued are the result of the application of an apartheid concept which was controlled by government policies thought the whole era of colonisation, as Fanny Colonna pointed out. (7) (8) Table 1.2.1. (ii) gives numerical support to this.

In the wider context the situation was even more disproportionate. In 1960, there were 1,059,581 settlers out of a total population of 10,704,309 and 81% of them (settlers) were living in urban centres, whereas 77% of the native population were restricted to deprived rural areas. (9) In addition, the settlers gained numerous socio-economical advantages and rights, particularly in education and in technical and organisational occupations, where they represented 70% of the labour force. (10) By contrast the vast majority of Algerian labour was working in the primary sector (e.g.: agriculture). (11) As far as the provision of buildings was concerned there existed only one university in the whole country located in the centre of the European quarter of Algiers, the capital. (12) This university was not initially conceived as such but it was given this status by the law of December 20th 1879 which gave the status of university to the existing four separate faculties in the capital (the Faculty of Medicine, the Faculty of Science, the Faculty of law and the Faculty of Arts). (13) Over the 132 years of colonisation, the French legacy in higher education in terms of infrastructures and achievements was unsubstantial. Unified premises for university buildings were unknown in Algeria until the early 1970s. (14)

1.2.2. The Post Colonial Period 1962-1971.

The democratisation of education, the 'Arabisation' not at the expense of foreign languages, the introduction of more options into the curricula with much emphasis on scientific and technological orientations on the one hand and the link between education and the social life on the other make up the back bone of the educational policy. (16)

The teaching content was progressively Algeranised to enable a gradual reconciliation of the university with the guidelines of the development of Algeria. (17)

Since the early years of independence the Algerian government has placed much emphasis on scientific and technological disciplines to fulfil basic needs for infrastructures (e.g. schools, universities, hospitals and health care facilities, airports, etc.) and economic growth as well as independence and national identity.(18)

Table 1.2.2. (i):**Hierarchical Structure of Education During the Colonial Era (1830- 1962)**

Social Origins	Type of Educational Establishments	Careers
Colonial Elite: Kadis & Officer	Primary School Secondary School	Liberal Career: Doctor & Lawyer
Aristocracy & Rich Peasants	University & Further Education	Business & Teacher
Small Merchants & Craftsmen	Koranic Schools & Rural 'Zaouiates'	Arabic teacher
Poor Peasants & Working class	Islamic Universities Of Neighbouring Countries	Imam & Mufti (Clergymen)

Source: Colonna F., Instituteurs Algériens 1883-1839,
(Paris, Presse de la fondation des Sciences Politique, 1975), p.87.

Table 1.2.2. (ii): **Proportion of Algerian Students in Higher Education During the Colonial Era.**

Years Disciplines	1929	1947	1954
Medicines & Pharmacy	13	72	101
Sciences	14	43	62
Law & Economics	17	61	179
Arts	33	82	165
Total	77	258	507

Source: Touati S., La Formation des cadres pour le Development,
(Alger, Office des Publications Universitaires, 1983), pp.59-60.

This was to be achieved by improving the methods of education, with greater use of laboratories and audio-visual amenities, greater concern with analysis and dialectic, by opposition to the traditional reliance on education by rote, and finally by greater emphasis on self-reliance among students.(19) It was argued that it was not enough to train the maximum number of students that the country required in different fields, but it was also necessary for the trained men to make a qualitative contribution, and this implied the setting up of a framework impregnated with national social and economic realities to deal with Algeria's specific problems.(20) In order to achieve these aims considerable investment in university buildings was imperative. From the early days of freedom Algeria has faced serious problems in providing sufficient university buildings to house the increasing number of students. During the first decade following independence the number of students increased considerably as can be seen from Table 1.2.2.

Table 1.2.2. (iii): **Growth in the Number of University Students During the Decade of 1962-1972.**

Years Designation	62-63	69-70	71-72
Women	579	2683	5540
Men	2230	9063	18794
Total	2809	11746	24334

Source: Ministry of Information & Culture, Ten Years of Achievements: 19th June 1965 19th June 1975, Chapter Education, (Algiers, 1976), p.8.

As the student population was increasing dramatically on the one hand and the existing university accommodation becomes saturated on the other, the provision of additional accommodation to meet the ever growing demand was vital. To overcome the problem, a massive conversion scheme of a number of existing buildings took place.(21) For instance, the Air Force base of Es-Senia was converted to provide accommodation for 4000 students and the military hospital of Constantine was converted to provide accommodation for 2000 students (Institute of Architecture, Institute of Dental surgery and the Veterinary Institute).(22) In Algiers , the cinema 'Le Capri' became a lecture theatre, a building in Rue Trolard and the 'Revoli' building were both converted into halls of residence with a capacity of 200 rooms each.(23)

According to a number of personal interviews with the sponsoring body officials, the provision of university buildings was made more difficult by the shortfall of buildings materials, and the lack of experience, expertise and design staff at both central and regional levels.(24) the extent of the lack of skills can be profiled back to the fact that on the eve of national independence only 12% out of a total student population of 5,000 were Algerians.(25) Furthermore,

> **90% of French settlers, administrators, technicians, doctors, teachers, contractors, and other skilled workers left the country. Factories and shops had closed down leaving 70% of the population unemployed. The war had resulted in the destruction of most public buildings such as hospitals, schools and there was particular harm caused to Algiers central library by the French Secret Army (O.A.S) in 1962. (26)**

In order to meet the increasing need for physical accommodation, strenuous measures were undertaken by central government within national plans of development (e.g. Economic Plan of Development).(27) However, owing to the difficulties set out above, Algeria turned to foreign firms for help in physical planning and architectural design.(28) (29) (30) Despite these efforts the number of university buildings required to meet targets was not fully achieved e.g. at Constantine and Oran universities.(31)

Interviews carried out by the author of the present thesis when doing the graduation final project on the building site of ‘Laghouat University’, coupled with available evidence, indicated three potential reasons behind the inability to provide the adequate number of university buildings. First the usage of highly sophisticated industrialised systems by foreign firms in the construction of this building type did not match Algerian potentialities and realities (e.g. paucity of technological resources resource and shortage of building materials). Secondly, there was a shortfall of skilled manpower and design staff (there existed only one Algerian architect in the country in 1962). (32) Thirdly, according to the nature of the projects known as ‘Projects Cles en Mains’, the client was excluded and implementation, hence gaining no benefit from the experience.(33) Moreover it was the foreign firm which ‘capitalised’ on a new experience to its credit. The lack of experts at all levels and particularly in the field of architecture has been critical throughout the independence era, as can be seen from Table 1.2.2.(iv) below for the year of 1969:

Table 1.2.2.(iv):**Proportion of Architectural Firms Practising in Algeria in 1969.**

Practising Nationality	Number	Proportion %
National	04	09.1
Private	05	11.4
Mixed	00	00
Foreign	35	79.5

Total	44	100

Source: Benmati N. A., L’habitat du Tiers Monde: Cas de l’Algerie, (Alger, Office des Publications Universitaires, 1982), p.222.

1.2.2.1. The Organisation of the Traditional University.

The existing Algerian university in 1962 was organised in four separate faculties, namely: the Faculty of Medicine, the Faculty of Law, the Faculty of Sciences and the Faculty of Sciences and the Faculty of Arts.(34) These faculties were snowed under by huge waves of students, creating a state of crisis. The faculty system was called into question when some criticisms were put forward by the Ministry of Higher Education and Scientific Research (M..E.R.S). It was argued that firstly, the system culminates in the over spreading of the human element available for teaching. Secondly, each faculty had a tendency to live in vacuum and sever ties with neighbouring faculties. Finally, it led to distorted development of research activities undertaken within each faculty.(35) The existing university was criticised for being a place where theoretical aspects of sciences were developed, whereas the practical uses to which these sciences could be put were either neglected or rejected.

In addition, the teaching programmes’ content did not take into account the country’s realities through new curricula options.

1.2.2.2. The 1972-1984 Era and the Advent of Higher Education Reform.

1.2.3.1. Foundation of higher Education.

The reform of higher education occurred in parallel with a radical change in the country’s economic system. This drastic change made possible the recovery of control over Algeria’s national resources and over all levers of the economy. It needed a new educational system which in turn implied a new structural framework for education. It was argued that it was inconceivable to have socialist management of enterprises applied to the units of production, while ideas and thoughts irrelevant to the Algerian context were still being taught within the university premises.

The higher education reform carried out in 1971-1972 was the crowing of a decade of efforts. The reform describes a university ‘outside the model that has come in from abroad’, ‘a university which does not set its objectives and orientations intrinsically and unilaterally; on the contrary, it receives them from the society in which it is based and which alone gives it life, meaning and reality.’ (36) To fulfil these aims, an education directed towards the development needs of the country was set up, the university was organised into specialised institutes (e.g. Institute of Pure and Applied Sciences and Institute of Biological Sciences). The teaching programmes e.g. for philosophy, history, economy and law were revised, as well as the length of training for university diplomas and degrees, taking into consideration the scientific and technical demands of the posts the students would later occupy.

1.2.3.2. Algerian Universities With the Advent of Reform.

Since the existing university division into faculties could not adapt the subjects being taught to the needs of the country, it therefore became urgent to abolish the faculty system and to set up a university which would function on the basis of principles which would enable it to be the prime mover in the field of the country’s economy.(37) Along these lines, higher education reform brought about the concept of an integrated university. The determining objectives of reform were put forward by the former Ministry of Higher Education Mr. Benyahia S. when facing the press in July 1971 he pointed out that, ‘the idea of integration is dealt with at two main levels’:

i) The integration of training programmes (subjects are integrated into the economic life of the community).

ii) The integrated of structures (each institute takes general responsibility for its teaching and research activities but none will be self-contained, so that students will receive instruction from and in institutes other then their own).(38)

1.2.3.2.1. The Integration of Training Programmes.

The purpose is to channel the training programmes provided in the university towards specific occupations in the various sectors of economy.(39) The occupations are defined in terms of their essence, which breaks down scientific knowledge according to its operational definition. For example, a position in management would require basic theoretical knowledge in some fundamental fields such as economy, law, statistics and accountancy to enable the specialist to monitor problems related to his profession.

1.2.3.2.2. The Integration of Structures.

The restructuring of the curricula and the introduction of more options could not occur within a university which based its organisation on isolated and autonomous entities (faculties). The faculty system, more and more criticised, was succeeded by the new concept of a university integrated into society. The university was no longer free to devise training programmes regardless of the context in which they occurred. It has become the country’s economy which sets out the needs for all kind of executives orientating and guiding henceforth the content of all university teaching programmes.(40) (41)

The specialisation of university institutes is the main feature of the integration of structures. The architectural structures were organised to allow optimum use of spaces and flexibility in university accommodation. This required a rational policy of investment for the building of lectures theatres, laboratories and classrooms. Each institute contains a set of specialised laboratories and equipment which can be used by students who have chosen very different training programmes. Lecture theatres, classrooms and other multi-use spaces are grouped together and constitute a joint holding for the entire university. They are not assigned solely to one or another university institute. This is the main organisational novelty to be incorporated in the building of a totally new set of university buildings.

1.3. Physical Development.

Up to 1970 very few projects in the tertiary field of education were undertaken. The Constantine University development plan was the first comprehensive scheme ever to be launched in the whole history of Algerian higher education. It is argued to be the major instigator of higher education reform and in effect the start of a large scale development of higher education.(42) A study conducted by Zaidi established two factors that support this argument: firstly, it revealed that the Brazilian development group that originated the Constantine University brief took part in the elaboration of the reform guidelines and secondly that the project provided ‘the inexperienced M.E.E.S with some valuable information’ in the sphere of university planning and design.(43) Two other major development plans immediately followed the Constantine one. These were located in the capital, Algiers, and Oran respectively. Yet by the late 1970s all three campuses were immersed as the student population again increased dramatically, illustrated in table 1.3. to overcome this situation two major measures were assayed by the M.E.R.S

1.3.1. The Emergency Programme.

This programme derived from within the second National Development Plan (1970-1973). Its main purpose was to cater for the ever growing demands for tertiary education by means of proliferating ‘Centres Universitaires’ nation-wide. Yet, by the beginning of the 1980s, according to the M.E.R.S annually survey there was a shortfall of some 20,000 university places.(44) This aggravated the situation and led eventually to the setting out of the ‘Carte Universitaire’.

1.3.2. The ‘Carte Universitaire’.

The major architectural operations laid down by the 'Carte' are of four different categories. Designing and building i) big or major universities and teaching hospitals, ii) institutes and 'Centres Universitaires', iii) extensions and maintenance to items one and two and iv) laboratories, equipment and furniture.

Even this second emergency measure did not ease the problem that had build up since the mid-1970s. further, delay in the formulation of the 'Carte' affected badly the implementation of many development plans. Oran University is a case in point. (45)

1.4 New Trends in the Provision of Universities.

A national map of the projected distribution of university buildings was drawn up in March 1984, to provide for universities all over the country.(46) Some important changes occurred as new types of organisation and curricula were introduced.(47) A strong emphasis upon scientific and technological disciplines was set out in the map guidelines, requiring a new type of university accommodation as well as new teaching methods to be able to translate these priorities into design solutions.(48) The existing universities, formerly called 'Centre Universitaires' were to be replaced by a new type of university: 'National Institutes of Higher Education'. These are said to specialise according to regional needs and specifications and fall into two main categories. The first type are called 'National Institute of Science and Technology' and the second type are called 'National Institutes of Medical Sciences' and are a part of the hospital building programme.(49)

This new trend in higher education policy is seen by central government as an essential requisite. First, to counter the increasing student population in the various fields of science and technology, shown in table 1.4. Second, to expend the higher education network throughout the country, balancing provision between the regions. Third since there is a serious lack of senior executives in the fields of science and technology (e.g. architects, engineers, physicians, chemists, biologists and geologists), considerable investment in specialised laboratories, workshops and libraries is required. (50) However, there are difficulties in getting on with the architectural and technical studies needed to provide this particular type of university building as the national university map required.(51) Even two years later in June 1986 there was still a persistent shortfall mentioned in the later design guidance.(52) The plight became more critical in the light of the university map which forecast an increase in the number of university townships to 28, each one specialising in a specific scientific and technological fields.(53)

Table 1.4: **Forecast Proportion of Students in the Fields of Science and Technology**.

Year	Proportion %
1985-86	33.5
1986-87	40.0
1987-88	48.0
1988-89	55.0
1989-90	60.0

Source: Ministry of Higher Education, Deploiement de la Carte de la Formation Superieur Horizon 2000: Annexe 12, (Algiers, May 1984), p.190.

1.5. Education System.

The education system established from the period of 1962 onwards has many positive achievements. It has greatly contributed to the training of students for the civil service. This was the major beneficiary of the spread of education and the expansion of centres for the diffusion of knowledge. Yet, along this spectrum of time, serious problems arose and many shortcomings appeared. Among the most serious was that the multidisciplinary approach, thought to be important so that students while pursuing their specialisation become more aware that they could not function without the knowledge of other sciences (if they wish to avoid intellectual sclerosis and dogmatism, and considered the ‘sine qua non’ of the development of sciences), proved to be ineffective. Interviews carried out with students at Constantine University revealed that this approach failed for to three main reasons. First there was a lack of interest by students who concentrated on their main subject to the detriment of secondary modules. Secondly, there was a lack of relationship between the ‘core module’ and the secondary ones. Finally, the heavy time-table and high density of the training programmes made students selective in their interests.

In addition, despite the free access to university which has increased the number of qualified Algerian people, some deficiencies appeared. First of all, the transition from an elite education to a mass education was slow, in part because, the form and the content of the programmes as Tlemcani argues did not change significantly from the inherited one. (54) Yet the concept of an education which segregates academic training from a practical one is in total contradiction to the guidelines of higher education policy. Reasons at the heart of this ‘malaise’, invoked by group of researchers from the Centre National de la Recherche

Scientifique (C.N.R.S) in Paris, are threefold. First the lack of experts and material resources.(55) Second, the provision of university buildings could not keep pace with the increased number of students. Thirdly, no major change occurred in the design of the universities to answer responsively to the new requirements implied by the reform.

1.6. Design Guidance.

Up to 1975, there existed no design guidance or space standards for architects of university buildings outlining what was required in terms of design and architectural aspects, neither of the policies underlying education or expectations of the university users. In 1976, design guidance for university buildings was introduced by central government.(56) The main feature of this guidance was the introduction of mandatory space standards which are still in use.(57) It also stipulated that university buildings (Centres Universitaires) should accommodate three separate institutes namely: Pure and Applied Sciences (2500 students), Social Sciences (1000 Students) and Biology (500 students). The prescribed size was 4000 students of whom 2200 were to live in student halls of residence. The total area of the programmed academic buildings was 23741.88 sq.m, students' accommodation 22,000sq.m, and communal facilities including catering, shops and sports fields 16259 s.q.m and administrative area 1112 sq.m. (58) All universities have chosen land outside urban areas, because there is a critical shortage of urban sites to accommodate such big projects. Analysis of the guidance in question indicated an array of deficiencies and lack of detailed information in relation to:

i) The sitting of this very complex and particular type of buildings.

ii) Space requirements of space which houses a particular activity, including specific dimensions, planning module, amount of the allocated area per student according to the discipline and to the year of course, and allocation of academic spaces to each institute and department house.

iii) The type of furniture and range of associated facilities needed, for instance, to perform adequately science laboratories procedures.

iv) Environmental attributes of the spaces including delighting factor, acoustic and noise control, fire and safety requirements and ecological hazards (which could stem from the use of chemicals and toxics materials).

v) Potential for growth and change in the institution's activity system.

Vast expenditure is now being allocated to university buildings in Algeria, regardless of what has been achieved in the field so far. In addition, new design guidance was issued in the year 2000 to provide a ready reference of information, while in the meantime the already existing 'Centres Universitaires' are being converted to house the increasing needs in the fields of science and technology. (59) The 1986 design guidance has not progressed significantly either to meet users' requirements or to accommodate the new type of activities set out by the educational reform, for these were not assessed. The guidelines were not drawn up from reliable information deriving empirically from users needs and requirements, but simply from 'fortuitous' governmental decisions. It has simply reproduced the same ergonomic data including the type and the number of institutes to be implemented or converted. (60) Many university buildings are still being built but the question remains, do they meet users' requirements?

1.7. Identification of Problems.

In Algeria university buildings are built by the state. In order to speed up the construction of universities a unified design guidance is used. (61) This attitude was intended to make a positive impact considering the repetition of the same requirements for each university. The reduction of variety should not only be considered from the design process point of view. It should be expected to bring about a change in attitude to the production of standard building components or functional elements. This tendency which aimed at simplifying only the design has caused many defects in application. Firstly, it was difficult to assess demand, secondly there was the nature of the design guidance, thirdly there was a lack of expertise, and lastly there was a lack of appropriate evaluations and documented studies.

1.7.1. The Difficulty of Assessing Demand Adequately.

From the first national development plan servicing the period 1967-1970 until the second plan fifth launched in 2005, central government has not been able fully to accomplish its aims and the supply of higher education accommodation has always been insufficient. The accumulation of shortages has made the provision of university accommodation inadequate to satisfy the registration of new students difficult to achieve.(62) As a result it has affected first, the students' working and living conditions, second, the quality of the built environment and third the allocated budget of the universities. An excessive amount of money was spent to fit up and maintain sufficient accommodation for the beginning of each academic year. (63)

The difficulty of assessing demand was mainly due to the lack of background research for a clear higher education plan and there existed no national university map which set out the nature and type of demand throughout the country. In addition, delays in implementing projects created a very uncomfortable situation, on the extent that the imbalance and overcrowding in the main four universities of the country (Algiers, Constantine, Oran and Annaba) reached an alarming point e.g. riots &s strikes as a result of a persistent deterioration of studying and living conditions. (64)

1.7.2. The Nature of Design Guidance.

Central Government has produced up to now two design guidance directives for university buildings. It could be supposed that the latter directive would contribute, to a certain extent, to an improvement of the content of the guidance towards a better understanding of university design problems and hence leads to the provision and production of a better built environment. Unfortunately, this is not the case, for neither of the two guidance directives is explicit or comprehensive. Both set out **'surfaces programmatic'**, or more specifically ergonomic data, including guidelines for the amount of space permitted for particular functions and activities. They also imply that this building type will mainly provide academic spaces and few other supporting facilities. The new design guidance has not favoured an assessment of faults that occurred in the former one. It has not expended the content to include new specifications and requirements in order to bridge the gap. In addition, it has shown the same rigidity as its predecessor in that any deviation from the prescribed building programme is viewed with some alarm.

It emerges clearly that the nature of such design guidance can hardly contribute to monitoring the design of such complex buildings. Furthermore, in Algeria where forecasts of the future in higher education are notoriously inaccurate and the continuing need to take such education to a greater number of people is increasing as fast as ever, there appears to be a lot to be done to provide university accommodation taking into account the qualitative aspects of the built environment.

1.7.3. Lack of Expertise.

After the French pulled out in 1962, Algeria suffered a lack of skilled manpower and experts in various fields of the economy.(65) Since then central government has been concerned to provide an adequate number of highly trained executives and experts. Though the figures are very encouraging, the need for foreign experts and advisors in strategic fields (e.g. economics, education), as pointed pointed out by the fifth National Development Plan (1980-1984), is still a vital necessity. (66) National Institutes of Higher Education are built on the basis of common guidance including standardised buildings regardless of regional specificities, particular architectural forms and the availability of appropriate building materials. The fifth development plan has also revealed some other problems. These are firstly, that architects who are in charge of the design of university buildings lack specialised knowledge and understanding of the complex relationships between an ever changing need (education) and a provision (built environment). And secondly, the training model adopted for building technicians was out dated, to the extent that the trainees, as Tlemcani argued, proved to be ‘useless’ with the emergence of new building techniques.(67) (68)

1.7.4. Inappropriateness of Evaluation and Documented Studies.

There is little specialised work and literature about evaluation and appraisals of university buildings in relation to their various architectural aspects. Evaluative studies, for which the Architectural Branch of the Ministry of Higher Education is held responsible, have always been characterised by being unable to encompass the different variables entering into the design process of universities. The emphasis is much stronger on meeting quantitative than qualitative needs.(69) Many gaps in the guidance has yet to be bridged (sect. 1.6.); the provision of continuous and specific information which derives from rigorous evaluative works and empirical evidence to architects and other mainly concerned with the design of this building type are either unreliable or non-existent. Reliable statistical data, documented university briefs and plans are either non-existent or inaccessible to architects. Other associated omissions are studies which might show to what extent university buildings are adequate to actual government policy or how far the actual design guidance meets users’ and built environment requirements and the extent to which existing universities (Centres Universitaires) could be adapted to meet the new requirements.

1.8. The Scope of Research.

At present there exists an exceptional opportunity for improvement in practically all spheres connected with university buildings in Algeria. Universities are attempting by various means to meet the challenge of a socio-economic ‘take off’. The urgency to quest for sustainable and yet performance based buildings is an ultimate goal and an utmost requisite constraints of a today information based society that aspire for best in a world of ferocious contest in an unforeseeable paths.

Architecturally the problem is not less monumental. The rapid expansion and the pace with science evolve in conjunction with the incongruity of both the functionalist and the formalist approaches with the realities of higher education requires that researchers and designers almost rethink approaches to the planning and design of university buildings. ‘University buildings are highly dynamic institutions’. (70) Further, studies surrounding this subject indicated that laboratories are the university accommodation most prone to change as well as the most expensive to provide, enhance, renovate and run.

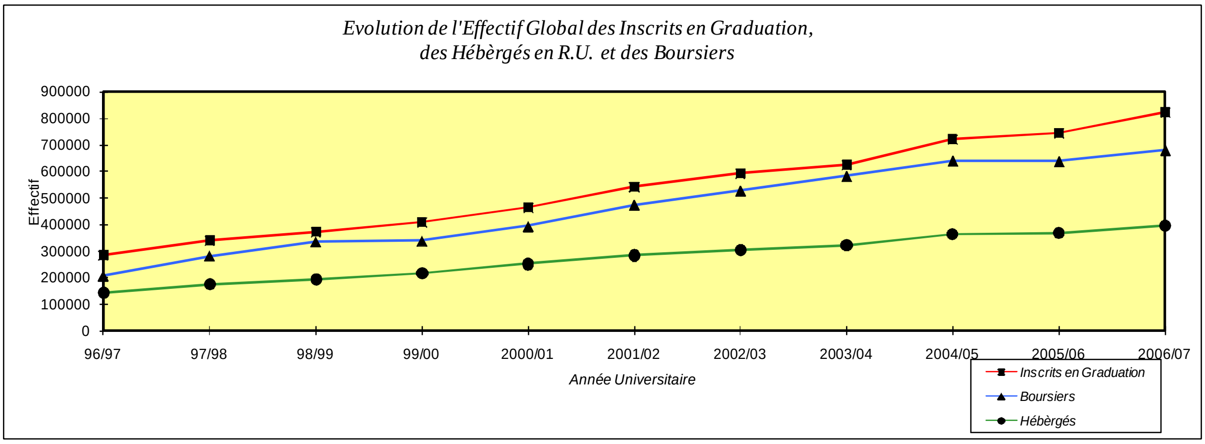
The subject of university buildings is a wide one and it would be virtually impossible within the scope of this study to encompass all, or even a large part of the various architectural facets involved in the design of these institutions. It is therefore felt that a more valuable contribution can be made by restricting the scope to a particular space with special reference to university buildings.

The argument for devoting this study to university science laboratories is threefold. First, the need to provide adequate terms of reference for this particular type of university accommodation, which stems from the ultimate priority attributed by central government to the provision of science orientated university buildings (sect.1.4), is considered central in Algerian education policy in order to set up an educational basis for challenging the ever growing complexities of modern life. Secondly, there exists a chronic deficiency of authorities in the field of laboratory design in Algeria. Finally, the resurgence of interest world-wide in the topic of laboratory design, to improve health, safety and efficiency standards, brought to light the complexity of having to design for the needs of an immediate use and yet having to incorporate in the design process of university science laboratories a potential for flexibility and adaptability. This to be able to mitigate, to a certain extent, the effects of change in the activity’s requirements, and the resultant uncertainty, upon the building. Accordingly, the change in the pattern of university teaching methods, the development of new scientific experimental techniques inherent to change in technology and the growth of students’ numbers which gave rise to intractable problems, call for diligent attention and close control over key issues of science laboratory built environment. These include efficiency and functional adequacy particularly in combing flexibility, safety, cost effectiveness and quality of environment. The recognition of these overall requisites has caused science laboratory design to become a major challenge and therefore merits a special study.

1.9. Summary.

Inherited facilities in higher education in Algeria were insubstantial and inadequate. Major emphasis was given after independence by central government to education. The continuous growth in the student population strained university facilities, yet university education was viewed as the key factor to socio-economic ‘take-off’. The inadequacy and paucity of the design guidance issued in the form of a building programme has not made the task easier for those who are involved in the planning and design of university buildings. Strong emphasis is put upon the disciplines of science and technology. To help ease the demand in technological fields, two major developments ensued. First, a massive conversion of existing university facilities to house the ever-increasing student numbers in science-based subjects took place, though there was no evidence of any feasibility study to assess the extent to which the available building stock is compatible with the proposed new use. Second, a vast expenditure is now being allocated to accommodate students in the scientific disciplines, using as terms of reference the already existing design guidance directives. Quantity has taken precedence over quality see below figures (1.9.1& 19.2.).

Figure 1.9.1: **Evolution des Effectifs Durant la Décade 96/97 à 2006/2007**



Source : WWW.MESRS.DZ 2008 (site visited august 2008)

Figure 1.9.2 : **Capacités Pédagogiques par Région**

Capacités Pédagogiques par région	Programme de Soutien à la Croissance 2005-2009	Programme Complémentaire 2005-2007	Programme Spécial du Sud	Programme Spécial Hauts Plateaux	TOTAL
Centre	169 100	4 000	1 000	2 000	176 100
Est	197 800	5 000	6 000	12 200	221 000
Ouest	102 100	16 000	3 000	6 600	127 700
	469 000	25 000	10 000	20 800	524 800

Source : WWW.MESRS.DZ 2008 (site visited august 2008)

Further, it appears that the nature of such design guidance can hardly contribute to monitoring the complexity inherent in this building type. It is essential therefore to improve the quality of design guidance. This study seeks to investigate the design of university science laboratories worldwide in order to enhance qualitatively the content of the Algerian design guidance in current use and subsequently to suggest a suitable framework in terms of planning and design requisites that could govern future Algerian university science laboratories built environment. Far from being deterministic, by studying problems implicit in the design of these spaces it is also intended to ease, to a certain extent, the translation of the prescribed design requirements into physical design especially as the building programme will expand massively in the coming few years. The characteristics of the design guidance are set out in the appendices to this thesis.

To achieve the set out above aims, international expertise and experience were considered relevant for two main reasons. The first stems from the extensive research and practice carried out in both European countries and the USA in the field of university science laboratories respectively. The second and preponderant reason centres on the ease of access to data. It was thought inconceivable not to examine the relevance of established norms and standards through a case study before extrapolating any of those to the Algerian context. The practicality of this procedure was made possible particularly with a great opportunity to cross compare data in the forgoing field on one hand. Where as on the other, it is a remarkable exercise that of compiling data to fulfil a shortage in scientifique based information.

For academic labs, the passive, front-facing lecture/ discussion room is becoming obsolete, yielding to the team-based interactive learning theatre where everyone can see the faces and hear the words of all in the room and those connected by the web. At Wallenberg Hall at Stanford University, there is no fixed furniture and the space can serve formal presentations, dynamic team based activities and support virtual concerts. Rooms like this are designed to allow small teams to work together in addition to dynamic full room discussions. Sophisticated audio speakers and microphones, image capture cameras and immediate digital connections to science communities around the world are the norm. In medium-to-large lecture rooms, triple projector screens are common with combination rear projection and or flat panel monitor systems often served by multiple computers with a single wireless control for the lights, blackout screens, and electronic media. These environments allow a view of the audience with the room fully illuminated; a view of the remote location; and a view of the information being shared in any combination, while capturing the entire event for future use.

The rapidly increasing accessibility of digital technology also has changed learning space design. Digital technology continues to advance at a frenetic pace, offering greater capability while simultaneously becoming more mobile and more affordable. Five years ago, most students purchased desktop computers; two years later, most purchased laptops. The implications are significant: more affordable and mobile technology facilitates greater access to content and resources. This enhanced access, in turn, has made it possible to implement a learning paradigm that emphasizes active learning, formative assessment, social engagement, mobility, and multiple paths through content. Although specific technologies may come and go, the enduring trend is technology becoming more capable, affordable, and mobile. Buildings are deceptively complex. At their best, they connect us with the past and represent the greatest legacy for the future. They provide shelter, encourage productivity, embody our culture, and certainly play an important part in life on the planet. In fact, the role of buildings is constantly changing. Buildings today are life support systems, communication and data terminals, canters of education, justice, and community, and so much more. They are incredibly expensive to build and maintain and must constantly be adjusted to function effectively over their life cycle. The economics of building has become as complex as its design.

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CHAPTER TWO:
CURRENT DEVELOPMENTS IN THE DESIGN OF LABORATORY FACILITY

2.1 Introduction

This chapter seeks to underscore righteously tough current developments in relation to the design of university laboratory facility which made the way trough in the prevailing literature during the decade running from the 1990’s onwards. To achieve this purpose we shall examine all emerging issues that could influence the design of laboratory facility. At present a new model of laboratory design is emerging, one that creates lab environments that are responsive to present needs and capable of accommodating future demands. Several key needs are driving the development of this model:

- The need to create "social buildings" that foster interaction and team-based research;
- The need to achieve an appropriate balance between "open" and "closed" labs;
- The need for flexibility to accommodate change;
- The need to design for technology to provide access to electronic communications systems throughout the building, which has immense implications on lab design;
- The need for environmental sustainability; and
- The need, in some cases, to develop science parks to facilitate partnerships between government, private-sector industry, and academia.(1)

2.2. The Laboratory Precinct As "Social Buildings"

Modern science is an intensely social activity. The most productive and successful scientists are intimately familiar with both the substance and style of each other's work. They display an astonishing capacity to adopt new research approaches and tools as quickly as they become available. Thus, science functions best when it is supported by architecture that facilitates both structured and informal interaction, flexible use of space, and sharing of resources. . (2)

2.3. Meeting Places

A critical consideration in designing such an environment is to establish places—break rooms, meeting rooms, atrium spaces—where people can congregate outside their labs to talk with one another. Even stairways, fire stairs, or stairs off an atrium with built-in window seats can provide opportunities for people to meet and exchange ideas. Designers must look for opportunities for such uses in public spaces, making optimal use of every square foot of the building. (3)

Figure 2.3. **The Laboratory Precinct an Example of Meeting Places**

Source: American National Standard 2005

2.4.Team-Based Labs

Collaborative work requires teams of scientists with varying expertise to form interdisciplinary research units. As networks connect people and organizations, sharing data within a team and with other research teams becomes less complicated. (4) So, designers are organizing space in new ways. Laboratory designers can support collaborative research by:

Figure 2.4.: **Team-Based Labs**

Source: American National Standard 2005

- Creating flexible engineering systems and casework that encourage research teams to alter their spaces to meet their needs

- Designing offices and write-up areas as places where people can work in teams
- Creating "research centers" that are team-based
- Creating all the space necessary for research team members to operate properly near each other
- Minimizing or eliminating spaces that are identified with a particular department
- Establishing clearly defined circulation patterns
- Provide interior glazing to allow people to see one another.

2.5. "Open" Versus "Closed" Labs

An increasing number of university institutions are creating "open" labs to support team-based work. The open lab (see bellow figure) concept is significantly different from that of the "closed" lab of the past, which was based on accommodating the individual principle investigator. In open labs, users share not only the space itself but also equipment, bench space, and support staff. The open lab format facilitates communication between scientists and makes the lab more easily adaptable for future needs. Accordingly, Daniel Watch pointed out that a wide variety of labs—from wet biology and chemistry labs, to engineering labs, to dry computer science facilities—are now being designed as open labs. Most laboratory facilities built or designed since the mid-1990s in the U.S. possess some type of open lab. (5)

Figure 2.5 **"Open Labs"**

Source: R&D Magazine 2005

There can be two or more open labs on a floor, encouraging multiple teams to focus on separate research projects. The architectural and engineering systems should be designed to affordably accommodate multiple floor plans that can easily be changed according to the research teams' needs. Closed labs are still needed for specific kinds of research or for certain equipment. Nuclear magnetic resonance (NMR) equipment, electron microscopes, tissue culture labs, darkrooms, and glass washing are examples of equipment and activities that must be housed in separate, dedicated spaces. (6) Moreover, some researchers find it difficult or unacceptable to work in a lab that is open to everyone. They may need some dedicated space for specific research in an individual closed lab. In some cases, individual closed labs can directly access a larger, shared open lab. When a researcher requires a separate space, an individual closed lab can meet his or her needs; when it is necessary and beneficial to work as a team, the main open lab is used. Equipment and bench space can be shared in the large open lab, thereby helping to reduce the cost of research. This concept can be taken further to create a lab module that allows glass walls to be located almost anywhere. The glass walls allow people to see each other, while also having their individual spaces. (7)

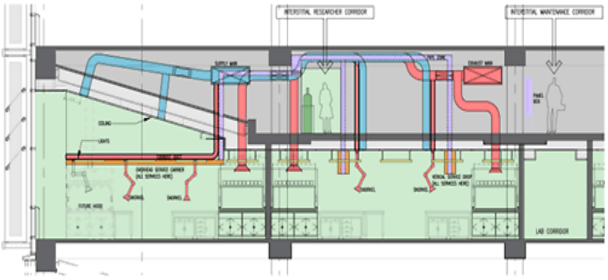
2.6. Flexibility

Maximizing flexibility has always been a key concern in designing or renovating a laboratory building. Flexibility can mean several things, including the ability to expand easily, to readily accommodate reconfigurations and other changes, and to permit a variety of uses.

2.6.1. Flexible Engineering Systems

Flexible engineering services (as in bellow figure) —supply and exhaust air, water, electricity, voice/data, and vacuum systems—are extremely important to most labs. Labs must have easy connects/disconnects at the walls and ceiling to allow for fast, affordable hook-ups of equipment. The engineering systems may need to be designed to enable fume hoods to be removed or added, to allow the space to be changed from a lab environment to an office and then back again, or to allow maintenance of the controls outside the lab. (8)

Figure 2.6.1. : **Flexible Engineering Systems**



Source: American Institute of Architects 1999

From the start, mechanical systems need to be designed for a maximum number of fume hoods in the building. Ductwork can be sized to allow for change and growth and vertical exhaust risers provided for future fume hoods in the initial construction. When a hood is required, the duct can simply be run from the hood to the installed vertical riser. (9) The mechanical systems will need to be re-balanced when a fume hood is added or deleted to efficiently accommodate the numbers of hoods in use and the air changes necessary through each room. Vertical risers are primarily used for the hoods that exhaust special chemicals (such as radioactive and perchloric fumes) that cannot be mixed into the main laboratory exhaust system. Installing vertical risers during initial construction takes little time and costs approximately one-third of what it costs for retrofitting to add vertical risers later on. Engineering systems should be designed to service initial demands and at least an additional 25% for anticipated future programs. Space should be allowed in utility corridors, ceilings, and vertical chases for future heating, ventilation, and air conditioning (HVAC), plumbing, and electrical needs. Service shutoff valves should be easily accessible, located in a box in the wall at the entry to the lab or in the ceiling at the entry. All pipes, valves, and clean-outs should be clearly labelled to identify the contents, pressure, and temperature. (10)

2.6.2. Equipment Zones

It typically takes about three years for a 10,000 square meter lab building to be designed and built. During this time an organization's research needs may change or the people doing the research may leave and be replaced by others. In either case, there is a good chance that the purpose of the lab will change. If the entire lab is fitted with new casework, the casework may have to be changed before anyone occupies the new lab. (11)

Figure 2.6.2.; **Equipment Zones**

Source: R&D Magazine 2005

To minimize this problem, equipment zones should be created in the initial design. An equipment zone is an area that can be fitted with equipment, movable furniture, fixed casework, or a combination of any of these. Equipment zones are usually fitted out when the research team moves into the lab—that is, when the team knows exactly what will be needed to do the work. The creation of equipment zones that accommodate change easily is a cost-effective design opportunity. The lab can be generic, with 50% casework initially and the rest of the lab fitted out later. The casework is usually located on the outside wall, with islands defined as equipment zones. It may also be helpful to locate 3 ft to 6 ft equipment zones on the outside walls to accommodate cylinders near fume hoods and refrigerators at the perimeter. (12)

2.6.3. Generic Labs

When a laboratory facility is designed generically, all the labs are the same size and are outfitted with the same basic engineering services and casework. Generic labs are a sensible option when it is not known who will occupy the space or what specific type of research will be conducted there. Generic lab design may also make sense from an administrative standpoint, since each team is given the same basic amenities. (13) The best generic labs have some flexibility built in and can be readily modified for the installation of equipment or for changes to the engineering services or casework. Many new labs are designed with mobile casework everywhere except for the fixed fume hoods and sinks. (14)

2.6.4. Mobile Casework

Technological advances allow for more research procedures to be automated. In the past equipment (see figure bellow) was often squeezed into an existing lab setup; today's labs must be designed to accept the needed equipment easily. There are several types of movable casework to consider. Storage cabinets that are 7 ft. tall allow a large volume of space for storage and can be very affordable, compared to the cost of multiple base cabinets. Mobile write-up stations can be moved into the lab whenever sit-down space is required for data collection. Mobile carts make excellent equipment storage units. Often used in research labs as computer workstations, mobile carts allow computer hardware to be stacked and then moved to equipment stations as needed. Data ports are also located adjacent to electrical outlets along the casework. Instrument cart assemblies are designed to allow for the sharing of instruments between labs. (15)

Figure 2.6.4.: **Mobile Casework**

Source: R&D Magazine 2005

Carts are typically designed to fit through a 3 ft. wide doorway and are equipped with levellers and castors. Many mobile carts are load tested to support 2,000 lbs. and can be designed with 1 in. vertical slots to support adjustable shelving. The depth of the shelving can vary to allow efficient stacking of equipment and supplies. Mobile base cabinets are constructed with a number of drawer and door configurations and are equipped with an anti-tipping counterweight. (16) The drawer units can be equipped with locks. The typical height of mobile cabinets is 29 in., which allows them to be located below most sit-down benches. Also, mobile tables are now available for robotic analyzers and designed to support 800 lbs. A mobile cabinet can also be designed to incorporate a computer cabinet, which can be hooked up to the robotic analyzers. Carts incorporate a pullout shelf for the server and a pullout tray for the keyboard in front of the monitor. Wire management is designed as a part of the cart. (17)

2.6.5. Using the Full Volume of the Lab Space

Many labs today are equipment intensive and require as much bench space as possible. Using the full volume of the lab space to stack equipment and supplies can be very helpful and cost-effective. Mobile carts, as mentioned earlier, can be used to stack computer hardware as well as other lab equipment. Overhead cabinets allow for storage above the bench, making good use of the volume of a space. Flexibility can also be addressed with adjustable shelving instead of cabinets. Adjustable shelving allows the researcher to use the number of shelves required, at the height and spacing necessary. (18) If tall equipment is set on the bench, the shelving can be taken down to allow space for the equipment. The bottom shelf should be 19-20 in. above the bench top and should stop 18 in. below the ceiling to permit appropriate coverage by the sprinkler system.

Figure 2.6.5. **: Full Volume of The Lab Space**

Source: R&D Magazine 2005

2.6.6. Overhead Service Carriers

An overhead service carrier is hung from the underside of the structural floor system. The utility services are run above the ceiling, where they are connected to the overhead service carrier. The utility services that are run above the ceiling should have quick connect and disconnect features for easy hook-ups to the overhead service carriers. Overhead service carriers come in standard widths and accommodate electrical and communication outlets, light fixtures, service fixtures for process piping, and exhaust snorkels. (19)

Figure 2.6.6.; **Overhead Service**

Source: R&D Magazine 2005

2.7. Wet and Dry Labs

Research facilities typically include both wet labs and dry labs. Wet labs have sinks, piped gases, and usually, fume hoods. Wet labs require chemical-resistant countertops and 100% outside air and are outfitted with some fixed casework. Dry labs are usually computer intensive, with significant requirements for electrical and data wiring. Their casework is mobile; they have adjustable shelving and plastic laminate counters. Recirculated air is sufficient. (Dry lab construction is, in fact, very similar to office construction.) A key difference is the substantial need for cooling in dry labs because of the heat generated by the equipment. (20)

2.8. Design for the Computer

One important change that has occurred in the design of research facilities is that furniture must be designed with computer use in mind. For example, furniture must accommodate the cabling necessary for PCs or laptop computers (as seen bellow). Tables should be modular so that they can be added to or rearranged consistent with the fixed casework and the lab equipment to meet criteria for the space. Ports and outlets should be located to accommodate multiple furniture layouts. Write-up stations should to be at least four ft wide to allow for knee space and hardware under the countertop. (21)

Figure 2.8.: **PCs or laptop computers**

Source: R&D Magazine 2005

Workstations should be 48 in. wide and 30 in. deep, at a minimum. If a computer will be shared, the workstation should, at a minimum, be 72 in. wide and 30 in. deep. In wet labs, computer keyboards must be placed away from spill areas, ideally in separate write-up areas. Laptop computers should be considered for their compact size, mobility, and ease of storage. Electrical outlets must be accessible for plugging in adapters. And, as was mentioned in an earlier section, designers should consider stacking hardware vertically on mobile carts. Laptops with voice-activated microphones are being developed for use in fume hoods, where use of standard laptops can create safety hazards (or where laptops might be damaged by chemical spills). (22)

Three key developments in computer furniture should be emphasized:

- Specialized equipment enclosures.
- Computer hardware enclosures. Hardware enclosures that are fully ventilated and secure are available. Security for computers in a lab is a management and design issue, and designers should consider mobile cabinets with adjustable shelving that can be locked.
- Monitor arms, server platforms, and keyboard drawer solutions. Monitor arms are capable of holding up to 100 lbs. and can support computer monitors of up to 21 in. Mobile server platforms are designed with adjustable shelving to allow stacking of computer hardware. Keyboard platforms can be adjusted vertically and can be mounted under the work surface.

2.9. Virtual Labs

Throughout the research community today, one constantly hears the phrases "virtual labs" and "virtual reality." Virtual labs will become more common each year. Some of the areas in which virtual reality will play a key role in future research are these: (23)

- Virtual manufacturing
- Three-dimensional calibration for virtual environments
- Assembly path planning using virtual reality techniques
- Virtual assembly design environment
- Knowledge-based systems
- Virtual environments for ergonomic design
- Telerobotics

2.10. Sustainability

A typical laboratory currently uses five times as much energy and water per square foot as a typical office building. Research laboratories are so energy-demanding for a variety of reasons: (24)

- They contain large numbers of containment and exhaust devices
- They house a great deal of heat-generating equipment
- Scientists require 24-hour access
- Irreplaceable experiments require fail-safe redundant backup systems and uninterrupted power supply (UPS) or emergency power.

In addition, research facilities have intensive ventilation requirements—including "once through" air—and must meet other health and safety codes, which add to energy use. Examining energy and water requirements from a holistic perspective, however, can identify significant opportunities for improving efficiencies while meeting or exceeding health and safety standards. Sustainable design of lab environments should also improve productivity. Key aspects of sustainable design are as follows:

- Increased energy efficiency
- Reduction or elimination of harmful substances and waste
- Improvements of both functional and environmental requirements
- Efficient use of building materials and resources

At this respect a full chapter is devoted in endeavour to fulfil the many features related in the incorporation of potential of sustainability in the provision and design of university laboratory facility. (25)

2.11. Science Parks

The partnering of research between the public and private sectors has been the main reason for the development of science parks (figure bellow). Four major trends that will impact science and technology parks of the future are: (26)

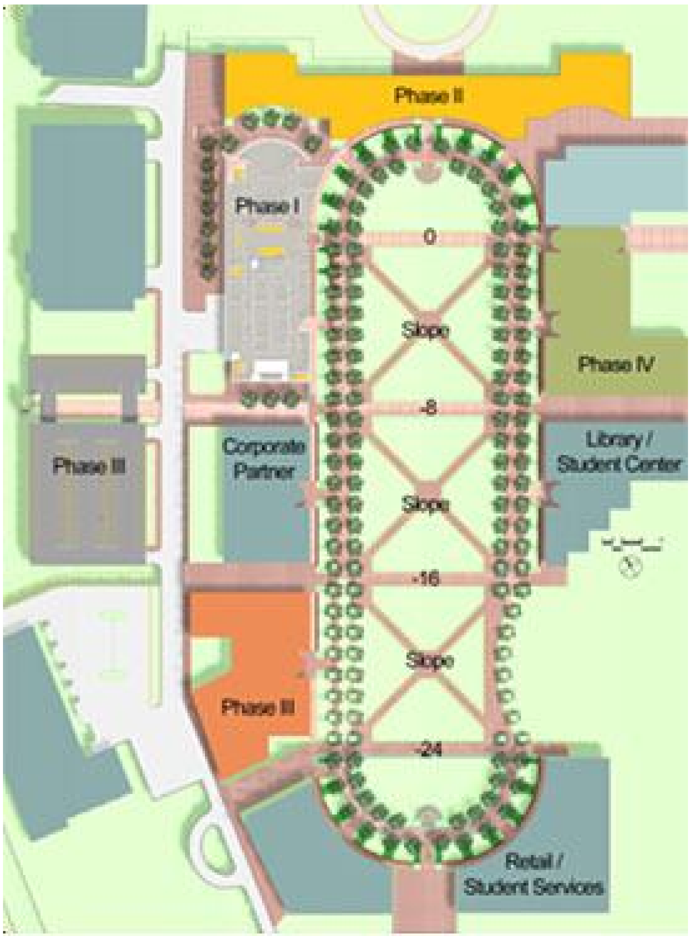
- Networking relationships with other science parks around the world having similar interests
- Increased use of Internet communication

- Increased focus on corporate incubator facilities
- Increased globalization of trade

Several key issues affect the choice of a science park's location:

- The proximity to research universities (almost 90 percent of research parks are located immediately adjacent to a university)
- The availability of a highly educated workforce
- Quality of life of the nearest city
- Proximity to a major airport
- Types and variety of research-based companies in the area
- The ability to expand at the same site.

Figure 2.11.: **North Carolina State University Centennial Campus:900,000 sf., College of Engineering**



Source: R&D Magazine 2005

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CHAPTER THREE:
DESIGN REQUIREMENTS OF UNIVERSITY LABORATORY FACILITY
SECTION ONE:

3.1. Introduction.

This chapter will focus on the design requirements that govern the design of university laboratory facilities as well as examining the current attitudes in the design of these buildings. A interrelated structured discourse appeared to be patent and of great opportunity in order to frame sound and yet utmost understanding that is urgently and acutely required in the field of planning and design of university laboratory facility. The forgoing converse will be split into two interrelated sections. While the first part will discus those requirements specifically in relation to the physical setting of laboratory facility the second part will in return be devoted solely to those requisites that could impede environnemental performance if left out or overlooked as merely influential factors into the design of such facility.

Henceforth the ongoing chapter intends I) to examine the rise of university laboratories, II) to examine the laboratory taxonomy (with regard the type of activity) in use and III) to identify major physical attributes of university science laboratories, including specific space standards (e.g. area per student, gangways, modules, etc.), furniture and equipment and fourthly to outline the environmental attributes that control laboratory design, namely: services, structure, noise control, acoustics, day lighting factor, fire safety, ventilation, and related hazards.

3.2. The Rise of University Laboratories.

As never before, the laboratory building is now considered ‘the form for advancement in very many areas of knowledge, the environment in which the most creative minds must function and it represents significant national, corporate and institutional investment in the future’. (1) Developments of thoughts and ideas about the design of laboratories were concurrent with the advent of the Renaissance. The most significant outcome was the ‘break from the tradition established by alchemists’. (2)

Thereafter, modern chemistry developed and many laboratories were erected Europe-wide as a development away from alchemical workshops. Though the first teaching laboratory brought to light took place in Britain precisely at Oxford in 1959. Yet, the foundation in 1960 (one year later) of the Royal Society is argued to be the major milestone in the development of university science laboratories in this country. Early laboratories emerged from conversion of existing buildings and consisted of one or two rooms. The apparatus was, to a large extent, like that of alchemists. It consisted of furnaces grouped at one side of the room, while a set of tables provided the required support for heavy and complicated apparatus and equipment. (3) More and better equipped laboratories came into use in universities by the mid-nineteenth century. These are believed to have been markedly influenced by Liebig's model, whose main feature lies in the fact that for the first time benches, as Weeks explained, 'become the base for often very elaborate arrays of apparatus using electricity, compressed air, steam, demineralised water and section, all available from a services manifold'.(5) Henceforth the concept of a 'laboratory, work bench-based' become a permanent feature in laboratory design.

At present, though the 'design and layout of laboratories accommodation has evolved continuously throughout the centuries in an endeavour to provide facilities which are suitable for the purpose required', (6) the unfortunate fact is that laboratories are far from being the adequate and stimulating environment that would match and meet potential users' requirements. (7) The change in the pattern of university teaching, the development of new scientific techniques and the progress of technology gave rise to inextricable problems. These relate in the main to laboratory efficiency and functional inadequacy particularly in combining flexibility, safety and environment sustainability. (8)

Laboratory facilities are complex, technically sophisticated, and mechanically intensive structures that are expensive to build and to maintain, and therefore the design, construction, and renovation of such facilities is a major challenge for all involved. Hundreds of decisions must be made before and during renovation or new construction. These decisions will determine how successfully the facility will function when completed and how successfully it can be maintained once put into service. Yet many of these decisions must be made by users and administrators whose knowledge of basic and more laboratory specific design, construction, and renovation is minimal at the start of the project and must be rapidly increased. (9) Laboratory design has been the subject of a bulk of literature, respectively from the National Research Council (NRC, 1930, 1951, 1962) and guidelines prepared by the National Institutes of Health and the American Institute of Architects (NIH, 1998; AIA, 1999). These books, however, addressed to the professional design community, whose members are already familiar with general design and construction issues and processes. Therefore we shall focus on the detailed specifications for a successfully constructed laboratory. In this context, a successful laboratory facility is defined as one that provides effective and flexible laboratories, is safe for laboratory workers, is compatible with the surrounding environment, has of the neighbouring community and governmental agencies, and above all one that can be constructed in a cost-effective manner. (10)

3.3. Laboratory Taxonomy.

Although, in the currently fashionable terms of categorisation, laboratories fall into three categories I) laboratories for scientific and medical purpose, II) research laboratories for the study and development of new possibilities and III) routine or service laboratories for the control and test of products, a much more inclusive classification is given by Musgrove. Writing in the January 1965 edition of the Architects' Journal (AJ) he suggested that in addition to the activity criterion, two more criteria are needed in classifying laboratories: the scale and the discipline respectively. Today this (9) this nomenclature simply split into two broad categories dry and wet laboratories. The following account discusses these criteria separately.

3.3.1. Laboratories Classified According to Activity.

3.3.1.1. Teaching Activity.

Teaching laboratories are spaces largely devoted to the instruction of students in the basic sciences during their undergraduate period. In England, university teaching laboratories, unlike research and routine laboratories are controlled by standards issued by the Laboratories Investigation Unit (L.I.U) in partnership with the D.E.S. The size of a science teaching laboratory varies from that needed to accommodate 10 to that for 100 students. The size of the laboratory depends mainly on the teaching method as well as on the number of students involved. (10)

The nature and use of science teaching laboratories has been strongly influenced by such factors as the traditional divisions into scientific disciplines, the conventional boundary between the theoretical and practical aspects of science, the preoccupation of most teaching departments with the training of science specialists and the immobility of much laboratory equipment [over the past few years in this country]. (11)

At present, there is a growing tendency towards the adoption of a more flexible teaching laboratory concept; laboratories that are 'multi-purpose' and 'multi-discipline' are favoured in many parts of the world (e.g. USA and France). Reasons claimed to have contributed to the genesis of this new attitude are twofold. Firstly, 'to reduce the human vacuum in science departments' and therefore 'to minimise the very low efficiency of utilisation of science teaching laboratories'. (12) (13) Secondly, to incorporate many technological tools in the process of teaching in conjunction with changes in the curricula; this implied that science teaching laboratories have to be fitted to suit various academic purposes. (14) (15)

3.3.1.2. Research Activity.

Scientific knowledge, particularly in recent years, has evolved in unforeseen venues, and in seeking to understand new topics, scientists have evolved with new methods which in turn markedly influenced their working environment. The very peculiar nature of the research activity made 'research laboratories a much more unpredictable category' of buildings than the concept outlined above in paragraph 3.3.1.1. (16) The possibility of diversification or change in use in addition to the fact that researchers involved in experimental research require both diligent control over and the ability to expand both their work is being carried out have made the case for flexibility and adaptability clear. (17) (18)

3.3.1.3. Routine Activity.

Routine, as the Oxford dictionary defines it, is 'a regular course of procedure, a more or less mechanical or unvarying performance of certain acts or duties'. (19) It ensues from this definition that the occurrence of an activity within a routine laboratory remains invariable over a period of time. This in turn led Musgrove to infer that 'user requirements will remain static' over a period of time. (20) However, he by no means claims that routine laboratory accommodation is everlasting and that therefore it 'can be tailor made for all times'; on the contrary he points to the slow pace of growth and change in routine laboratories. Subsequently the assessment of future needs can be achieved with some measure of accuracy. (21) Though the conventional fragmentation of science into chemistry, physics and biology in conjuncture with the limits of a conceptual theory based approach may prove of little significance to a designer in the field of laboratory buildings, yet Musgrove argued that its relevance lies in the fact that it gives us 'a simple framework into which all laboratory activities can be fitted, even though any one of the disciplines may combine techniques from the others'. (24) This 'simple framework' or 'generator', as Darke calls it, acts as a structuring device and a tool of inquiry, which will help to reveal facts and elements from which an initial space problem may originate, as well as to ease the breaking of design problems into manageable segments.(25) 'To serve the architect as a way into the problem' and 'to enable a start to be made' is how this approach is applied to laboratory design rather than claiming it to be a problem-solving method in the whole field of laboratory design. (26) (27) Details accounts of the three main disciplines introduced above is given in the corresponding appendices.

3.3.1.4. Wet Laboratories

Wet Laboratory space types are defined as laboratories where chemicals, drugs, or other material or biological matter are tested and analyzed requiring water, direct ventilation, and specialized piped utilities. Wet Laboratory space types do not include biohazards in Levels BL-2, BL-3, and BL-4 as defined by the 1999 NIH/CDC guideline "Bio safety in Microbiological and Biomedical Laboratories, » The Wet Laboratory space types are typically located within a building specifically designed to house them

Wet Laboratory space types are unique in that they must accommodate simultaneous and separate ventilation and utility connections at individual laboratory modules to ensure both the reliability and accuracy of results as well as occupant safety throughout the space. Typical Wet Laboratory space requires the design objectives elements as outlined below.

A Wet Lab space is typically divided into separate laboratory modules that contain individually controlled connections to HVAC, utilities and safety devices. Modules are defined spatially by floor-to-ceiling structural slab with under-floor plenum divider. The fittings and connections for each module are connected to the building distribution system for six nominal piping systems namely: vacuum, pneumatic supply, natural gas, O_2 and CO_2, and distilled water. It is also typical of this space type to include an acid and corrosives vented storage cabinet located under the fume hood, as well storage for emergency equipment.

3.3.1.5. Dry Laboratories

The Dry Laboratory space type is a laboratory space that is specific to work with dry stored materials, electronics, and/or large instruments with few piped services. The laboratories defined by this space type are analytical laboratories that may require accurate temperature and humidity control, dust control, and clean power. Dry laboratory space types are designed to accommodate project-specific work patterns and scientific equipment. As such, they tend to include design features that provide reliable working conditions in a somewhat mobile environment. Typical features of dry laboratory space types include the list of applicable design objectives elements as outlined below. For a complete list and definitions of the design objectives within the context of whole building design, click on the titles below. As some equipment and experiments are temperature-and humidity-sensitive, constant conditions are required in Dry Laboratory spaces to ensure that equipment can perform properly and that experiments produce accurate results. Laboratories are usually supplied. Just as experiments and equipment may be sensitive to changes in temperature and humidity, so might they be to dust and other foreign particulates.

3.4. Planning Considerations and the Design of Laboratory facility

3.4.1. Location.

Location is considered an important factor influencing design. ‘Teaching laboratories present architectural and planning problems’ inherent to both their peculiar nature and their being an integral part of the complex institution that is a university. Though various criteria have to be incorporated in the general location of science teaching laboratories, in order to move away from the trap of over-simplification and misinterpretation, two key variables are argued to be at the heart of their setting within the whole physical layout of the university. (28) (29) These relate to two main streams which Handler identifies as ‘environmental change’, which derive from a more general concept known as ‘functional obsolescence’, and ‘educational change’. (30) Both of these can affect the sitting of science teaching laboratories and ultimately the quality of the built environment. Instances of environmental change that could render buildings obsolete relate to the whole ecology of the campus, including noise (service yards and delivery points are often the source of irritating noise) and pollution (this phenomenon stems in the main from the use in laboratories of a great variety of chemicals, the use of dangerous substances and the use of bulky pieces of equipment).

Educational obsolescence, on the other hand, refers to the ‘misfit between the activities and the fabric’ as Heath pointed out. (31) A major criticism of early English university science teaching laboratories centred around the fact that they suffered a chronic lack of ‘space and improvisation’. (32) Furthermore, Mills argued that there is an urgent need not to design ‘too closely around prescriptions of an immediate use’ but ‘for a long term view of its operations’ thus to contribute to the ‘effective use of a laboratory throughout its life span’. (33)

One way to respond to unforeseen changes which are bound to occur is by vertical expansion. However, are bound to occur is by vertical expansion. However, this procedure ‘has not generally been found to match revised requirements’, for I) it is not cost effective and II) it causes severe disturbances to work in existing buildings. (34)

It therefore emerges that account should be taken of both criteria emerges that account should be taken of both criteria (environmental change and educational obsolescence) in predicting the likelihood and degree of change in attempting to formulate a flexible framework which could allow change in laboratories in response to complex forces, whilst giving sufficient guidance to facilitate immediate implementation.

3.4.2. Physical Attributes of Laboratory Space.

3.4.2.1. Space Standards.

Through the requirements for the three main science disciplines (chemistry, biology and physics) differ, particularly in terms of the equipment used and the pattern of the course, the recommendations embodied in the U.G.C's 'Notes on Procedures' are given by order of student 'seniority' rather than in relation to the subject taught. (35) The total amount of space allowed per student is given in table 3.4.2.11.

3.4.2.2. Laboratory Height.

Studies featuring laboratory height demonstrated that 'there is no need for making laboratories higher than other workrooms'. (36) This suggests that the required clear and unobstructed ceiling space in a teaching laboratory is 9ft. Further, the Nuffield Report revealed that a greater height proved to have pronounced adverse implications in relation to 'lighting, ventilation, working convenience and building cost'. (37) Exceeding the above dimension could therefore only be justified when dictated by the requirements of the work . (38) The Charles Darwin Building at Bristol Polytechnic is case in point, in it the introduction of the concept of loose furniture and overhead services led to a readjustment of laboratory height where; it was raised to 3.6m. (39)

Table 3.4.2.2: **Usable Area per Student According to their Year of Course**.

Year of Course	Usable Area Per Student (Sq.ft)
Elementary or intermediate	40
1st. & 2nd Year Honours & General	45
Final Year	60
Research Students in Groups of 4+	80
Advanced or Individual Research	120

Source: D.E.S & U.G.C., 'Notes on Procedures', Architects Journal, (03/02/1965), p.321.

3.4.2.3. The Module.

A module represents the smallest repetitive unit of space. It may be combined with other like units to form the typical elements of space (also called modules) that accommodates a variety of functions. (40)

Alexander and Ferguson argue that the advantages of the Modular planning in the field of laboratory design are twofold. The first is to facilitate the integration of complicated engineering services and the second is that the module is an important geometrical device whereby internal order in buildings is provided and flexibility in the context of laboratories is possible.(41) (42)

The Edinburgh Report on Laboratory Design argued that the choice of a module can influence greatly a number of design parameters such as fenestration, lighting and ceiling systems and therefore its choice requires a great deal of care and the consideration of overall functional needs in the early stages of the planning process. (43)

The choice of the size of the module in laboratory building is a two-variable function. It is determined by the combination of people at work (at bench) and the necessary space between two workers (gangway). (44) Generally a ‘satisfactory clean-cut layout can be planned with more than 3m but less than 4m’. (45) This practice can comply with the design of a building based on ‘a dimensional grid of 7.2m that is twice the dimension of the fundamental element of 3.6m’. (46)

3.4.3. Furniture and Equipment.

For many years laboratory design has been damned by inflexible hardware. Fixed furniture and equipment, which stem from the idea of a lasting laboratory, proved to hinder the provision of ‘a dynamic learning space’. (47) At present, ‘laboratory equipment and its associated services’ are argued to be a central key to the provision of an adaptable laboratory space and ultimately to be a preponderant element in providing flexibility. (48) The impetus towards recognising this, which originated in the work carried out by the Nuffield Group, has been further emphasised by the L.I.U. team. The former generated ‘a hardware system’ which ‘incorporates analysis of current predicted patterns of use’ as well as ‘up to date ergonomic data’. (49) One significant outcome brought about the introduction of the ‘loose furniture and overhead services’ concept in laboratory design. Though there was some scepticism about its effectiveness, its implementation in the case of the Charles Darwin Building at Bristol Polytechnic is argued to be a major ‘tour de force’ in laboratory design in this country. (50) (51) Additionally, the L.I.U demonstrated that fastening a bulky piece of hardware to the fabric freezes further changes in use. (52) It follows thus that the central factor emerging in the provision of a laboratory pattern is flexibility. This however must not be confined to one particular aspect of the laboratory environment but must include all compartments of the laboratory environment.

3.4.3.1. The Bench.

‘Whether standards or purpose made benches are to be used, this will have a major bearing on the areas of general laboratory module or room size. (53) There are three main types of benches: I) the movable, II) the fixed wall and III) the fixed island. More consideration has been given recently to a bench system embodying movable and standardised bench sizes so as to provide ease of adaptability and cost effectiveness. (54) Beside showing that there were anthropometric constraints that govern the width, height, length and the spacing between benches, the authors of the Nuffield Report established a set of potential bench measurements liable to change to suit new circumstances of laboratory work.

3.4.3.1.1. Bench Length.

Recommended bench lengths laid down by the AJ's editors are inclusive of sinks or other fixed equipment (if any) which form part of a bench run. (55) The table below gives bench lengths which differ according to the scientific discipline. There are three length categories: long for those activities requiring considerable lengths of bench e.g. biochemistry, medium for those requiring moderate lengths of bench e.g. chemistry, physics and biophysics. And short for those requiring short lengths bench e.g. botany and zoology. (56)

Table 3.4.3.1.1**: Bench Lengths According to Scientific Discipline**.

Discipline	Bench Length (ft.)	Length Category (ft.)
Biochemistry	11-15	Long
Chemistry, Physics, Biophysics, Pathology and Physiology.	10-13	Medium
Botany and Zoology	9-12	short

Source: Architects' Journal Editors, 'Laboratory Spaces, Fixtures and Equipment', Information Sheet 1312, Architects Journal, (03/02/1965), p.319.

3.4.3.1.2. Bench Height.

A study entitled 'Developing a Range of Adaptable Furniture and Services for Laboratories' carried out by Branton and Darke stated that bench heights are controlled by two key parameters. These are the 'relationship between the worktop to the seating height' and anthropometric constraints. (60) The set of recommendations laid down in table 3.4.3.1. (ii) takes account of both criteria.

Table 3.4.3.1.2.: **Recommended Heights for University Laboratory Facility Benches**.

Position	Bench Height (ft)	Seat Height (ft)
Sitting only	2ft 4in	1ft 5in
Women Either Standing or Sitting	2ft 10in	2ft 1in
Men Either Standing or Sitting	3ft 0in	2ft 3in

Source: Architects' Journal, 13 December, 1965.

3.4.3.1.3. Spacing Between Benches or Gangways.

While bench dimensions derive from the nature of the work, bench spacing is regulated by two major considerations: convenience and safety. Ferguson argued that a person at work 'should be able to pass another working at bench comfortably and without risk of collision if the latter should step back unexpectedly'. (61) Bench spacing varies according to a number of conditions of use. The British Standards suggest the specifications laid down in table 3.4.3.1. (IV).

Table 3.4.3.1.3: **Bench Spacing According to Conditions of Use.**

Conditions of Use	Recommended Spacing (ft.)
One worker, no through traffic.	3ft. 5in (1.0m)
One Worker plus passage way.	4 ft. (1.2m)
Two workers back to back plus passage way	6ft (1.8m)
Two workers back to back; no through traffic.	4ft 6in (1.4m)
Gangways only, no working spaces either sides.	4ft 9in (1.4m)

(*): Experience has shown that this figure is not enough; 5ft would be more satisfactory. AJ, 03/02/1965, p.322.
Source: British Standards No.3202.

3.4.3.2. Disposal Services.

Whatever precautions are advocated in laboratory procedure for the disposal of strong acids or alkalis and powerful organic solvents, it is almost inevitable that such materials… will from time to time find their way down the sink. (62)

For this reason, the provision of the laboratory waste system calls for a diligent choice of fittings and materials.

Measures for evacuating wastes and effluents relate to the nature of residuals, whether they are solid or liquid. Whilst ‘solid wastes are normally dealt with by local bins’, liquid waste on the other hand are generally released by means of sinks which are linked to draining boards. Decisions concerning the type of skins to be used (whether incorporated within the bench, conveniently placed but isolated, or a combination of alternatives) are argued to be connected to the availability of space on the bench, according to Ferguson. (63) (64) In England, in science teaching laboratories, incorporated sinks with a size of 12in* 9in* 6in are favoured rather isolated ones. (65) They should ‘preferably be connected to a receiver pot outside the laboratory, where the dilution factor is substantially increased’ in order to parry the unexpected hazards resulting from a mix of effluents and other toxic agents of different sources.(66) Detailed accounts of the main materials used for both sinks and draining boards with notes on their suitability for laboratory purposes can be found in the appendices to this thesis.

3.4.3.3. Fume Cupboards.

A fume cupboard, as the British Standard publication on Laboratory Furniture and Fittings defines it, is:

A confined working bench… equipped with services and provided with an efficient means of removing objectionable fumes, gases, vapours, etc, admitted into or generated within the confined space. (67) Though chemistry and biochemistry are considered as disciplines that make considerable use of fume cupboards, both the Edinburgh and Nuffield reports demonstrated that regardless of their function, science teaching laboratories must be provided with a least one fume cupboard, mainly for health and safety reasons.(68) (69) Braybrooke argued that the location of fume cupboards in laboratory premises is controlled by health, safety and flexibility requirements. (70) Mobile recirculatory fume cabinets, developed by the L.I.U’s for the case of Leicester project, proved to enhance the flexibility factor and to overcome the problems of installing new ductwork and fans within an exiting laboratory.(71)

3.4.4. Services and Structure.

One critical aspect associated with the provision of a services system within a laboratory centres on its relationship with the structure. Evidence stemming both from research and practice points to the fact that confining services to the structure has profound consequences for the overall efficiency of the laboratory. The significance of such findings led to the emergence of two fundamentally different recommendations for new laboratory design. Services must be segregated from the structure, or by contrast to other buildings, services for laboratory buildings should form the primary skeleton of the structure. (72)(73)

The L.I.U's paper number nine (09), which stems from a study at Bristol Polytechnic, put forward two main methods to contain the relationship between services and structure in the context of laboratory design. One is 'to allow the floor structure to take up the full floor zone with services running through the structural members'. The second is 'to allocate services and structure to separate zones'. (74) Decisions relevant to which of the two alternatives should be applied are governed by the behaviour of the structure in terms of fire requirements. (75)

3.4.4.1. Services.

Musgrove contended that:

> The provision of services has had a greater influence on the design of laboratories than on any other building type. The nature of the activity demands environmental control of unusual or special kinds. (76)

The complexity and expensiveness of servicing a laboratory engendered an architectural problem of major acuteness as services could have a critical impact upon laboratory design. Patterns of servicing a laboratory amount to three: i) vertical sub-main, ii) horizontal sub-main and iii) perimeter sub-mains. The significant variation within these systems is whether services are 'up-fed' or 'down-fed' to benches. (77)(78) The noticeable features of a vertical sub-main pattern are firstly the easy access to the various parts of the system from within the room it serves and secondly additional sub-mains can be added without undue disturbance to work. The one point that could detract from this pattern is that its cost effectiveness depends upon the extent of its use. A horizontal method, on the other, hand although recognised as the most economical system as well as allowing rooms on either side of a corridor to be serviced with ease, is not without its own Achilles' heel. In effect the maintenance of theses sub-mains is said to provoke disturbances in circulation areas. The perimeter sub-mains system derives from the horizontal sub-mains one, thus all that has been said about the latter could be applicable to it, and it has an additional disadvantage which consists in its failure to house runs 'without significantly reducing usable floor area'. (79) (80)

3.4.4.2. The Structure.

Laboratory structure is considered the element of laboratory environment most prone to change. A considerable amount of research carried out by the L.I.U. indicates that the setting of a precisely tailored structure, often intrinsic to an over-identification of the building with the work of the moment, inhibits future developments. (81)(82) Central to the requirements of the laboratory's structure is therefore its readiness and openness to innovation and change as new needs arise. (83) The point worth bearing in mind in attempting to approach the problem is not to regard the laboratory as a simple isolated object but to consider it as a complicated web of relationship of a unified whole (as for instance the relationship of the structure to services discussed in section 3.4.4) to avoid enhancing the cost. Secondly, there must be a clear distancing the cost. Secondly, there must be a clear distinction between 'the permanent and variable parts of laboratory' structure in the early stage of design, for, as both the AJ's editors and the L.I.U's paper number one have argued, ignoring the distinction could reduce the degree of adaptability possible and thus could eventually be prejudicial to the effective life of the building. (84) (85) Permanent structural features include frame, roof, bracing, load bearing walls, beams and floors while variable ones include partitions, fenestration and ceiling panels.

3.4.5. Environmental Attributes of Laboratory Space.

Laboratory design has evolved into a complex and highly specialised field, 'Within the stringent functional and safety standards to which laboratories must be designed, the quality of the working environment has become a major design challenge'. (86) Although the influence of the physical environment on human behaviour has been succinctly demonstrated, yet today's laboratories among other buildings are still liable to create environmental discomfort for the users. (87) Purcell argued that one major cause behind this 'malaise' is the frequent underestimation 'of the complexity of the physical environment, the complexity of the physical environment, the complexity of human experience and behaviour and the equally complex possible relationships between the two'.(88) Not surprisingly, although environmental designers have developed endless expedients to control the various environmental forces within a laboratory shell, the endeavour to provide an adequate 'milieu' wherein an activity can flourish, has failed to provide a responsive answer to the activity's requirements.

The authors of 'Building Performance' identify the entire environmental system as an organisation consisting of two main sub-systems. These are firstly the 'spatial environment' (those aspects mentioned earlier including space standards and various ergomic data) and secondly the 'physical environment-those aspects of the environmental system directly perceived as heat, light, sound, texture and smell'. (89) In the following paragraphs the latter set of laboratory space attributes will be given emphasis since the former has already been discussed. The aim is to examine what specifications, limits or criteria regulate some of the environmental parameters involved. The nub of the argument for adopting this procedure is twofold. The first, as Markus said, is to bring the problem into a manageable size while being aware of the associated complexity and the second is that it is beyond the scope of the coming sections to investigate the complexity inherent in a building's physical system.(90)

3.4.5.1. Noise Control and Acoustics.

Noise is a major source of both physiological endurance and psychological discomfort. Its effects relate to 'deafness, interference with communication and annoyance'.(91) The nature of an experimental scientific activity calls for a quiet environment for its adequate performance. Although the required degree of quietness is argued to be difficult to assess due to the interaction of subjective factors such the susceptibility of the users to sound, a number of measures can be taken in order to alleviate noise nuisance. The most important are I) planning measures II) structural precautions and III) reduction of noise in the laboratory by means of silencing devices.(92)

I) Reduction by Planning.

Clearly one way to screen the effect of external noise is to site the building 'as far as possible from troublesome sources'.(93) However, an account of the highly interactive nature of the various factors involved in laboratory design highlights the limits of such a simplistic procedure. Alternatively, a zoning policy for the sitting of university buildings is believed to be the most appropriate strategy to attenuate design conflicts inherent within the nature of the institution.(92) The key to this method centres around the concept of segregation, which implies the separation of 'clean' from 'dirty' areas and 'noisy' from 'quiet' activities. Means to achieve this latter result combine two criteria: the noise criterion and the use of buffer spaces e.g. stores and dark-rooms to reduce the propagation of sound.

ii) Structural Precautions.

Any structure is bound to satisfy minima in terms of resistance to the propagation of noise. At present, means of predicting the behaviour of a structure subject to a given source of noise from acoustic curves, to reverberation time and absorption factors.(95) Alongside the suggestion made by Parkin and Stacy to consider sound insulation in relation to 'the likely frequency encountered', to enable the designer to measure the required amount of insulation with reasonable accuracy, it is of prima facie importance to give significant attention primarily to the conflict implicit in the use of movable partitions (needed in some instances to achieve flexibility, although the value of their sound insulation is low) and secondly to view the entire structural system as a continuum because the various openings (doors, windows, joints, etc.) are major escape routes for noise. (96)(97)

III) Noise Reduction Within The Laboratory.

By contrast to the two previous measures, noise control at the source is argued to be less arduous. Yet noise emerging from the use of a corpus of appliances and equipment within the laboratory is often neglected, as Burberry pointed out.(98) Important in remedying such disturbances is a request for ‘noise emission data from the suppliers when purchasing new equipment’ and equally important is the use ‘silencing devices’ (finishes, baffles silent door closers, diaphragm valves, and anti-vibration mountings) where appropriate. (99)

3.4.5.2. Day lighting Factor.

Lighting is considered a major necessity in laboratory design. It is intimately connected to the nature of the activity, a great deal of which relies on visual observation and good seeing conditions.(100) The conventional measure of the required quantum of day lighting in a laboratory derives from the illumination level (the IES code stipulates 20 lumen/sq.ft for a general laboratory) which in turn stems from a percentage of a constant value of the outdoor illumination of 500 lumen/sq.ft.(101) The corresponding daylight level for a general laboratory amounts therefore to 4% of the outdoor illumination.

Wong observed that this predicative technique is not without its own Achilles’ heel in that i) ‘the sky is rarely under such uniform conditions’ and ii) ‘no consideration was given to reflections and inter-reflections which have since proved to add considerably to the illumination level of a room, especially in areas most remote from the fenestration’.(102) Furthermore, its failure ‘to define the full extent of the reality which it aims to represent’ beside showing its limitations as a model for measuring the day lighting factor, stresses the need to include the above variables when attempting to formulate the day lighting equation.(103)

3.4.5.3. Fire Safety and Hazards.

‘The rise of risk factor in laboratories is greater than in most other building types’ due in the main to the character of the activity in there. This involves the use of a wide range of dangerous chemicals, flammable liquids and other pathogenic materials. (104) Measures to provide for fire safety fall into two main categories, namely preventive and precautionary measures respectively.

I) The Preventive Measure.

This first measure involves the user's attitude towards fire and health safety in a laboratory environment. Both research and practice recognise that health and safety awareness can be notably increased 'first by an effective support of management and second by raising user's awareness as regards hazards'. (105) Yet, William says, many still subscribe to the idea that 'buildings are planned, constructed and equipped so that the risk of an outbreak of fire is minimal'.(106) Such a short-sighted attitude embodied a dangerous assumption that if fire requirements are provided then safety is ensured. Unfortunately this is far from being the case for 'no two fires are alike'.(107) Hence, it seems reasonable to highlight the primacy of providing fire-fighting equipment and to introduce the users the users to it, as well as raising users' awareness of fire hazards so as to lessen the impact of fire's outbreak. Failure to achieve this or excessive reliance on the building's fire resistance alone could thwart safety operations.

III) The Precautionary Measure.

The building Research Board argued that 'limiting the development and spread of fire in the event of an outbreak' whilst 'providing for safe exit of the occupants' are the ultimate goals at which a precautionary measure should aim.(108) To achieve these aims, William argued the centrality of two major steps: first, 'to ensure that adequate structural fire resistance is incorporated' within the building and second to fit the premises with enough fire exists.(109) The first factor means that scrupulous attention must be given to various building components in terms of their resistance to fire hazards. That is, to withstand consequential loss and undue damage, the structure must conform two main criteria: i) fire resistance and ii) restricting the spread of flames, smoke and gases.(110) The second factor is to provide for sufficient means of escape whereby users can get away with reasonable ease. The Nuffield Report outlined three main criteria believed to best regulate the placement of escape routes within the building:

a) the provision of sufficient and suitable located exits, particularly in relation to working stations.

b) Limitation of travel distance to exits.

c) The provision of corridors and staircases of adequate width.(111)

3.4.5.4. Ventilation.

It can never be over-emphasised that the nature of the activity in a laboratory is such that it requires farsighted environmental considerations of which ventilation is a major one. Its ‘raison d’etre’ stems in the main from health and safety reasons e.g. to extract the smoke and toxic gases that could be generated during the course of a laboratory procedure. (112) Less and Smith argued that adopting a one-way relationship between the external environment and a component of the internal environment in the provision of a ventilation facility appears to affect adversely the performance of both the fume cupboards and the heating system.(113) This illustrates the fact that decisions relevant to ventilation could have clearly undesirable environmental consequences. (114) Means of conveying ventilation to a laboratory space may be natural or mechanical. In the first case the quantum of indoor natural ventilation is directly linked to the size of windows and their location and orientation with respect to the prevailing winds. (115) In the second, due care in the selection of a mechanical ventilation system should be given to temperature fluctuation of the system. (116)

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CHAPTER THREE:
SECTION TWO

3.6. Physical Hazards

Furniture and cabinets/counters shall be designed to be as vertically flush as possible. Kneehole space shall be provided for waste containers. Both these approaches allow for better movement in the laboratory and increase safety. (1)

3.7. Casework

Laboratory casework shall be easily cleanable, and finishes shall be compatible with materials used for cleaning and disinfection. Metal casework systems shall be utilized in the laboratories. Minimum level of quality of casework is outlined in NIH Laboratory Casework Specifications, which are available from the NIH Project Officer.(2) Long runs of fixed casework should be minimized. Racked equipment, mobile casework on wheels, or other options that minimize cost and maximize flexibility shall be considered. The casework selected should be interchangeable and readily available so reconfigurations can easily occur. Shelving height is not to exceed 2 200 mm. For additional information on shelving layout and height, see General Design Guidelines, Section: Fire Protection. Fixed casework and countertops shall be sealed to walls and floors during installation to minimize harbourage of pests and provide a cleanable joint. Architects/engineers (A/E) shall also review caulking and sealing requirements with the Division of Safety, Integrated Pest Management Section, when designing NIH laboratory facilities. (3)

Countertop materials will vary depending on usage. Traditional materials such as chemical resistant plastic laminates may be appropriate for some applications. Epoxy resin will apply to most applications where corrosive chemicals are used or where sinks or heavy water usage occurs. Other new materials should be investigated for cost-effectiveness and durability. Stainless steel shall be used for glassware wash areas, cold rooms, and other areas as the program requires. (4)

3.8. Chemical Fume Hoods:

All containment devices shall be located in the laboratory to avoid entrapment, blocking of egress, or safety hazard to the lab occupant. For correct positioning of the fume hood, the designer shall follow the design methodologies in the NIH publication Methodology for Optimization of Laboratory Hood Containment to evaluate containment performance. (5)

3.9. Placement of Biological Safety Cabinets (BSCs) in Lab Module:

Personnel traffic results in air pattern disruption in BSCs. Therefore, BSCs shall be placed out of the direct traffic pattern of the laboratory. Air supply diffusers or exhaust vents shall not be placed directly over or in front of BSCs where the movement of air can affect the airflow of the cabinet. (6)

3.10. Equipment:

A wide variety of laboratory equipment is used to create adaptability in laboratory space so that instruments can be relocated within the laboratory without altering the space or attendant utility systems and without compromising the operation of the instruments or safety of the users. (7) Some instrumentation rooms, electron microscopy suites, MRI spectroscopy suites, x-ray crystallography suites, and mass spectrometry rooms require special utilities and environmental controls.

3.10. 1. Autoclaves:

For maximum flexibility, autoclave space shall be provided on each floor where microbiological research is performed. Actual installation of autoclaves and their use are an operational decision. Since quality control considerations may require separate autoclaves for clean and dirty procedures, space shall be considered for both clean autoclaves (for sterilization of microbiological media and clean instruments, etc.) and dirty autoclaves (for decontamination purposes). Autoclave space shall be finished with epoxy coatings and shall not have a suspended, acoustical ceiling. This area shall be thoroughly caulked and sealed to promote cleanliness and reduce pest harbourage. (8)

The space shall have adequate exhaust capacity to remove heat, steam, and doors generated by the use of the autoclave(s). A canopy hood shall be provided over the door of the autoclave. The autoclave space shall operate at negative pressure to the surrounding areas.

3.10. 2. Gas Cylinders:

Commonly used gases such as CO2 should be supplied from a centralized manifold or bulk storage tank and piped throughout the facility. All applicable warning gauges and valves with protective fusible links or the equivalent shall be included in the design. Some gases (flammable gases) may not be stored outside the laboratory. If cylinders are to be placed in the lab, they shall be properly secured to a vertical surface or counter out of the way of traffic in the space. Appropriate space for such cylinders shall be provided within the laboratory to minimize potential hazards associated with the use of these cylinders and to maximize usable laboratory space.(9)

3.10. 3.Flammable and Waste Storage:

Flammable-chemical storage cabinets shall be placed in each laboratory and meet applicable fire safety requirements. Space shall be allocated in each laboratory for waste box storage. (10)

3.11. Architectural Finishes and Materials

Design features and materials selected for the construction of laboratories shall be durable, smooth, and cleanable, provide ease of maintenance and minimize pest access, and contribute to the creation of a comfortable, productive, and safe work environment. Materials for laboratory finishes shall be as resistant as possible to the corrosive chemical activity of disinfectants and other chemicals used in the laboratory. Selection of materials and design of penetrations through walls and floors have an impact on fire safety in buildings. (11)

3.11.1. Floor and Base Materials:

Floor materials shall be non-absorbent, skid-proof, resistant to wear, and resistant to the adverse effects of acids, solvents, and detergents. Materials may be monolithic (sheet flooring) or have a minimal number of joints such as vinyl composition tile (VCT) or rubber tile. Floor materials shall be installed to allow for decontamination with liquid disinfectants and to minimize the potential spread of spills. (12)

3.11.2. Walls:

Wall surfaces shall be free from cracks, unsealed penetrations, and imperfect junctions with ceiling and floors. Materials shall be capable of withstanding washing with strong detergents and disinfectants and be capable of withstanding the impact of normal traffic.(13)

3.11.3. Ceilings:

Ceilings such as washable lay-in acoustical tiles (Mylar face with smooth surface or equivalent) shall be provided for most laboratory spaces. Ceiling heights shall be 2 850 mm in laboratory and laboratory support spaces and a minimum of 2 440 mm in administrative spaces. Gypsum board with epoxy paint ceilings, equipped with access panels, will be provided in glassware washing and autoclave rooms, where the potential for a high moisture level exists. Access panels shall be fitted with gaskets that seal the door when closed and also the flange around the panel lip where it meets the ceiling. Open ceilings are acceptable provided minimal ducting and piping are present and all exposed surfaces are smooth and cleanable. (14)

3.11.4. Windows and Window Treatment:

Windows shall be no operable and shall be sealed and caulked. Window systems shall use energy-efficient glass. (15) Treatments shall meet all functional and aesthetic needs and standards. All window treatment selections shall be coordinated with other interior finishes. Light-tight treatments will be provided in conference rooms, laboratories, and other spaces that may need to be darkened. Consistent visual appearance on the exterior of the building shall be maintained by the type of window treatment selected. (16)

3.11.5. Doors:

Doors into laboratories along a service corridor shall be 1 200 mm wide with 900 mm active leaf and 300 mm inactive leaf. (16) The door along the personnel corridor shall be a single-leaf 900 mm door. In the event no service corridor is planned, a double-leaf door along the personnel corridor is strongly recommended. Vision panels shall be provided in the active leaf of all laboratory doors. Doors shall be at least 2 100 mm high. In laboratories where the use of larger equipment is anticipated, wider/higher doors shall be considered. Laboratory doors shall be recessed and swing outward in the direction of egress. (17)

3.11.6. Door Hardware:

Laboratory doors are considered high-use doors. All hardware shall be appropriately specified to withstand this type of use. Light commercial grade hardware will not be specified. All appropriate hardware to meet security, accessibility, and life safety requirements shall be provided. Doors should be fitted with kick plates. Laboratory door hardware and keying shall comply with requirements outlined in General Design Guidelines, Section: Architecture. (18)

3.12. Structural

3.12. 1. Module/Bay Size:

The dimension of the structural bay, both vertical and horizontal, shall be carefully evaluated with respect to the laboratory planning module, mechanical distribution, and future expansion plans. Because of the importance of the laboratory planning module to functional and safety issues, the laboratory planning module shall be considered as the primary building module in multi-use facilities. (19)The horizontal dimension of the structural bay shall be a multiple of the laboratory-planning module dimension to provide for maximum flexibility and regular fenestration and to allow uniform points of connection for laboratory services with respect to the laboratory-planning module. (20) Columns shall not fall within the laboratory-planning module to prevent interference with laboratory layouts and inefficient use of valuable laboratory space. Close coordination between structural and mechanical disciplines is critical to minimize interference of piping and ventilating systems with the structural framing. (21)

3.12. 2.Floor Slab Depressions:

Floor depressions and/or topping slabs will be evaluated for use in special-finish areas or areas exposed to materials that may cause the structural floor slab to deteriorate. Floor depressions shall be reviewed for equipment requirements to allow for ease of movement of equipment. (22)

3.13. Heating, Ventilation, and Air Conditioning (HVAC)

HVAC systems shall be responsive to laboratory facility demands. Temperature and humidity shall be carefully controlled. Systems shall have adequate ventilation capacity to control fumes, doors, and airborne contaminants, permit safe operation of fume hoods, and cool the significant heat loads that can be generated in the lab. (23)

HVAC systems shall be both reliable and redundant and operate without interruption. Fume hoods will operate continuously. HVAC systems shall be designed to maintain relative pressure differentials between spaces and shall be efficient to operate, both in terms of energy consumption and from a maintenance perspective. Federal energy standards shall be achieved. An energy monitoring control system shall be provided. Studies shall be conducted during the design phase to determine the feasibility of utilizing heat-recovery systems in research laboratory buildings. (24)

Laboratory noise, much of it generated by HVAC systems, shall be maintained at an NC between 40 and 45 dB. Refer to General Design Guidelines, Section: Mechanical, for systems design, preparing a basis of design report, and energy conservation requirements. (25)

3.13.1 Lighting Loads:

The HVAC system shall provide, at a minimum, the following heat loads generated by room and task lighting: (26)

Table 3.13.**1 Lighting Loads**

Space	Task Lighting (W/person)	Room Lighting (W/nm^2)
Laboratories	**250**	**32**
Offices	250	32
Corridors	**NA**	**11**

Source: American Society of Heating, 2003

3.13.2 Occupancy Loads:

In the absence of more specific program requirements, the following occupancy loads shall be used as a general guide for HVAC calculations during the facility design. The A/E shall review the actual occupancy load and these general loads with the NIH Project Officer prior to starting the HVAC design work. (27)

Table 3.13.2 **Occupancy Loads**

Space	**Floor Area**
Offices	7 nm^2 per full-time employee (FTE)
Laboratories	10 nm^2 per FTE
Laboratory support areas, constant-temperature rooms, autoclave rooms, and glassware-washing rooms	22 nm^2 per FTE

Source: American Society of Heating, 2003

3.13.3. Ventilation Loads:

Table 3.13.3. **Ventilation Loads**

Space	**Ventilation Air**
Laboratory/laboratory support	6 air changes per hour minimum
Office/administrator support	9 L/s per person minimum

Source: American Society of Heating, 2003

3.14 Laboratory Equipment Cooling Loads:

The central HVAC system shall provide as a minimum cooling for 1 892 W of laboratory equipment per lab module or cooling for the actual calculated load, whichever is greater. NIH experience has shown that for a typical 22 nm^2 laboratory module, the equipment load is usually 1 892 W (sensible heat) or 86 W/nm^2. (28)

3.15. Normal Power:

The following load figures in W/m2 shall be used in calculating and sizing the overall building load. These figures are connected load and shall be used in the early design stages. Actual design loads shall be used in the later part of the design. The range provided allows for varying intensity of usage. The mechanical loads do not include chilled water or steam generation, which are produced centrally on the NIH campus. The engineer shall use sound judgment in applying these numbers. (29)

Table 3.15. **Normal Power Load Figures**

Load	**W/m^2**
Lighting	27-38
Receptacle	48-215
HVAC	97-108
Lab equipment	43-86
Elevators	11-16
Miscellaneous	11-22
Total Range	**237-485**

Source: American Society of Heating, 2003

Laboratories shall have a surface metal raceway mounted above all benches and as otherwise required in the room. Receptacles shall be mounted 600 mm on center in a continuous raceway above laboratory benches. Receptacles mounted within 1 m of water dispensing shall be the ground fault interrupter. One each lab module shall have two 20 A circuits for computers with a maximum of three duplex receptacles each. These computer receptacles shall be grey in color. (30)

3.16. Lighting:

Laboratory facility requires high-quality lighting for close work, in terms of both brightness and uniformity. Fixtures shall be positioned to provide uniform, shadow-free and glare-free illumination of the laboratory bench top. (31)

General lighting for laboratories shall be fluorescent fixtures. Incandescent lamps may be required for special purposes. Fluorescent light fixtures should be directly above and parallel to the front edge of the laboratory bench to prevent shadows. Local wall switches shall control light fixtures. Fluorescent lighting shall be circuited to 277/480V panels located in electric closets. Electrical loads for laboratory lighting should be approximately 2.5 W/m^2. Fluorescent light fixtures should be equipped with RF suppression type ballasts in instrument laboratories, where RF may interfere with instrument operation or be cold cathode-type of ballast located remotely. (32)

3.17. Biological Safety

Bio hazardous materials are defined as infectious agents, or materials produced by living organisms that may cause disease in other living organisms. While, generally speaking, the laboratory procedures identified as good microbiological techniques are helpful in minimizing potential occupational exposure to bio hazardous materials, containment of these agents through the use of good facility design is also extremely important. (33) The intent of this section is to provide A/Es with a working knowledge of the facility design parameters required for the construction of facilities, which shall provide for containment of biological hazards. (34)

The NIH guideline Biological Safety in Microbiological and Biomedical Laboratories provides guidance in the appropriate containment of bio hazardous work. Biological safety levels 1-4 have been designated, the least hazardous. The biological safety levels are based on the probability of occupationally acquired infections resulting from the handling of specific agents in the laboratory. Containment facility design and laboratory practices have been developed for each biological safety level to minimize the potential for personnel exposure and release to the environment. All NIH laboratories at a minimum shall be designed to meet the requirements of bio safety level 2 (BSL-2) containment requirements. (35)

3.18. Radiation Safety

Work performed at NIH laboratories involves the potential for occupational exposure to radioactive materials and other sources of ionizing and non-ionizing radiation. While laboratory procedures identify good radiation safety practices and techniques essential to minimize potential exposure to radiation, the security, containment, and shielding of this material and equipment through the use of good facility design are other extremely important elements. The intent of this section is to provide A/Es with a working knowledge of the facility design parameters required for the construction of facilities, which shall provide for the control and containment of these radiation hazards. (36)

3.18.1. Radioactive Waste Storage On-Campus Buildings:

Laboratory buildings on the NIH campus shall be designed with a separate area for the temporary staging of hazardous and radioactive waste. Mixed waste (hazardous waste that is also radioactive) shall be treated as radioactive waste in this temporary staging area. These staging areas are discussed in detail in General Design Guidelines, Section: Environmental. Only the specific issues that are directly related to radioactive waste are discussed here. Information on the carts and equipment for the transfer of radioactive waste currently in use can be obtained from the NIH Division of Safety, Radiation Safety Branch. (37)

The staging area shall be large enough to provide for temporary storage of the radioactive waste and capacity for storage of specialized carts used to transport the radioactive waste from the laboratories. The staging area shall be designed to contain any spills of radioactive waste that may occur during handling of the waste materials Coolers and/or walk-in freezers used to store MPW will also be used to store animal carcasses, tissues, and bedding contaminated with radioactive materials. Coolers and/or walk-in freezers shall be located in each building with laboratories conducting biomedical research with radioactive materials.

3.19. Summary.

The chief aim of the foregoing chapter was to outline the major design criteria that control university science teaching laboratories in England. In attempting to identify these criteria, attention was first drawn to the limits of the conventional laboratory design. Secondly, it emphasised two main streams of design prerequisites: i) those related to physical attributes of the laboratory space e.g. space standards, structure, furniture and equipment and iii) those related to the environmental ones e.g. services, day lighting factor, noise and acoustics, fire safety, and ventilation.

It has been argued throughout the chapter (sect.3.4.1, sect.3.4.2.2, sect3.4.2.3, sect.3.4.3. and sect.3.4.4.) that both sets of design criteria were intimately connected. Furthermore it urged the case for not considering the laboratory environment as an aggregation of isolated sub-entities but as a complicated web of relations between various parts of a unified whole. The centrality of flexibility and adaptability as preponderant design parameters in order to avoid hindering the preponderant design parameters in order to avoid hindering the provision of a dynamic learning space also emerged. (sect.3.4.1, sect.3.4.2.3, sect3.4.3, sect.3.4.3.1, sect.3.4.3.3, and sect.3.4.4.2.) These latter concepts will be thoroughly examined in the next chapter.

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CHAPTER FOUR :
GROWTH AND CHANGE AND THE PHENOMENA OF OBSOLESCENCE IN BUILDINGS

1. Introduction

Any facility can become obsolete, but those types of buildings that serve more rapidly changing activities (such as hospitals, laboratories, and educational facilities) are particularly susceptible to the problems of obsolescence. Public buildings are priceless assets that can provide decades of high-quality service if they are utilized effectively. Buildings are planned, designed, constructed, operated, and maintained to this end. Nevertheless, when a building is no longer fit to fulfil users' needs and requirements, foremost action is needed to overhaul, renovate, or even demolish. Change is at the crux of such turmoil in the life cycle of a building. (1)

Users may change and have requirements different from those the building was initially intended to fulfil. Change lead to rising expectations about the services and amenities that a building should provide. Rising expectations can arguably jeopardise the lifetime of a building and engender obsolescence. Moreover, as Krada claim's the loss of fit in the space/user interface can induce costly and heavy burdens... (2)

The Building Research Board based in London (BRB) pointed that '**Obsolescence is not a matter of design alone but must be considered within the context of a facility's entire life cycle, from initial planning through operations and maintenance.** (3)

Obsolescence can primarily occur as a result of external changes. Theses often are embodied in the adoption of new standards or codes, rising expectations of performance, major technological change, major change in functional requirements, major organizational change, shifts in property values, poor maintenance or abuse of systems, or aesthetic shifts. All these shifts are incentive for the rise of obsolescence.(4) Forecasting all change is impossible. It is rather to predict the like hood of obsolescence and hence to mitigate its effects on the building and users alike. Evidence stemmed from relevant literature points out that to accommodate unforeseen changes flexibility should be the key to all actions of: planning and programming; design; construction; operations, maintenance, and renewal; and retrofit or reuse. (5)

2. Definition Of Obsolescence

Webster's Ninth New Collegiate Dictionary (1985) traces the word "obsolete,"—meaning "no longer in use," "old fashioned," "vestigial,"—to Latin roots in the sixteenth century. "Obsolescence," the "process of becoming obsolete or the condition of being nearly obsolete," appeared much later—in the mid-nineteenth century.

Henceforth, one can understand obsolescence that condition of being antiquated, old fashioned, outmoded, or out of date. The obsolete item is not necessarily broken, worn out or otherwise dysfunctional, although these conditions may underscore the obsolescence. Rather, then the state of fit in the interface space/user is no longer viable. (6)

3. Causes of Obsolescence

Change in requirements or expectations regarding the shelter, comfort, profitability, or other dimensions of performance are typical, inevitable, and accelerated in pace. Often, to fulfil this matter of fact of brought in changes; modifications can prove costly because the designs of older structures are not adapted easily to new systems, finishes, and interior layouts. In extreme cases of obsolescence, it has been more cost effective to demolish and replace structures rather than renovate them. (7) Sometimes problems arise because design guidelines are outdated or do not address new requirements, sometimes, when new materials or products are emerging rapidly, there is a general lack of information upon which to base building decisions; and sometimes the slow pace of the federal budgeting process permits needs to shift while authorizations are sought to construct facilities for Which programming and design are complete already? All of these are causes of obsolescence. (8). Either bad design or programming can influence the onset of obsolescence. For example, use of inflexible partitioning systems or failure to maintain mechanical systems can hasten the time when users judge that a facility is no longer adequate for their needs, particularly if, at the same time, other facilities and mechanical systems offering better performance have become available. Thereafter obsolescence becomes a significant design and programming issue (9) However, more typically, over the years roofs need replacing, mechanical equipment breaks down, metals corrode, and sealants erode, regardless of users' needs, economic factors, or technological advances. These conditions are not obsolescence, although the repairs or replacements may incorporate materials or parts that use new technology and thereby defer or redress obsolescence. Whatever the cause, any element that has reached the end of its physical life has, in fact, failed and must be replaced, repaired, refitted, or abandoned. An element that has reached the end of its service life, on the other hand, can continue to function (albeit at less-than-adequate performance) and may or may not be replaced or refitted. Obsolescence can end the actual service life sometimes years before the designers anticipated that. The complexity of building systems defies definition of any single parameter adequate to measure all aspects of performance. Hence, to evaluate performance or obsolescence effectively, one must consider each functional system or subsystem. A number of factors, falling roughly into four broad categories, may cause rising expectations, obsolescence, and increased expenses: (10)

3.1. Functional factors,

Those related to the uses a building or spaces within the building.

3.2. Economic factors,

Referring primarily to the cost of continuing to use an existing building, subsystem, or component compared with the expense of substituting some alternative (e.g., when a building cannot compete effectively with its newer neighbours for tenants and rents);

3.3. Technological factors,

Referring to the efficiency and service offered by the existing installed technology compared to new and improved alternatives of extending the facility's service life. e.g.: when electrical power distribution and grounding systems are no longer able to accommodate the demands of current office automation); and

3.4.Social, legal, political, or cultural factors,

That is the broad influence of social goals, political agendas, or changing lifestyles (e.g., when a building fails to meet the requirements set in new legislation for accessibility by people with physical disabilities).

4. Strategies To Mitigate Obsolescence

Avoiding obsolescence or minimizing its costs can be accomplished through actions in planning and programming; design; construction; operations, maintenance, and renewal; and retrofitting or reuse of a facility (throughout the facility life cycle). These actions generally have the purpose of minimizing the impacts of obsolescence by anticipating change or accommodating changes that cause obsolescence before the costs of obsolescence become substantial. These costs, in turn, may occur at various times during a facility's life cycle and must be viewed within this total life-cycle context. (11) Above all of this, their growing outcry from those implicated in the design of such facilities that. Generally speaking, an essential element of professional responsibility for architects, engineers, and other building professionals is to keep abreast of new developments in their fields. Professionals who fail to do so can become obsolete themselves. However, the rate of change and growth of information in the building-related professions is such that individuals must work together so as to set up the best suited data base ever to managing obsolescence effects. (12)

4.1 Planning And Programming

It is impossible to foresee accurately all changes that will occur over the decades-long service life of a facility. Nevertheless, thoughtful planning and programming of a facility can do much to avoid early obsolescence, both for new construction or substantial reconstruction, by striving to assure that a facility's design is robust: capable of accommodating change without substantial loss of performance capability. Continuing to be alert to possible change is an essential prerequisite of effective management of individual facilities and facilities portfolios. (13) For designers a prerequisite in the construction of a building inventory, post occupancy evaluation (POE) is a valuable aid in programming. The POE yields an assessment of how well a facility's performance matches the design optima and users' needs. That assessment, typically made at the peak of performance (i.e., after the building's shakedown period), provides information useful in both management of the current facility and design of new ones in the future. Accumulated experience on (to adopt the term from statistics) to measure the sate of fit enables the designer to infill better and yet efficient understandings of obsolescence. (14) The adoption a POE tool is discussed lately in the forgoing thesis.

4.2. Predesign Scrutiny

Scanning and programming are preludes to facility design, and the consideration of future change should proceed smoothly from these prelude activities into design. Architect Richard Rodgers, for example, has made accommodation of change a basic element of his design philosophy:

“I believe that many architects misjudge the private needs of buildings. The rate of change in society—and you can pick the computer or whatever you want as a symbol—

makes long term prediction impossible and inflexible building unreasonable. A set of offices today may be an art gallery tomorrow. A perfume factory may switch to making electronics. What we can do—and this is the key to much of my work—is to design buildings that allow for change, so they can extend their useful lives....” (15)

Rodgers does this by separating the services from a building's usable space, making the services very accessible, and organizing the building so it does not have to close when the services are being renewed. (1991 Lloyd's building in London) One increasingly practical way to put such a philosophy into practice is by predesign scrutiny of major design options.

4.3 Actions In Design

The design stage of facility development is crucial in avoiding obsolescence in that it determines not only the spatial relationships of activities the facility serves but also the interactions among functional subsystems (e.g., electrical, telecommunications, and HVAC), each of which may be influenced by obsolescence in any of the others. And just as these subsystems are related, so too is design to avoid obsolescence tied closely to activities in construction and later stages of development, as well as to planning and programming already described. (16)

4.3.1 Design Guidance

Current design guidelines and building codes are prerequisite's of effective design to avoid obsolescence. But rapidly changing technology, compared to the relatively slow rate at which the professional community and responsible authorities are able to adopt new standards and regulations, makes it difficult or impossible for facility designs to be both up to date and in conformance with guidance in use. Many federal agency design manuals and guide specifications, for example, are reviewed and updated on a 5-year cycle. Other design guidance may be updated on different cycles. (Building Research Board, 1989,) A most notable case is the Salk Institute in La Jolla, California, designed by Louis Kahn and built between 1964 and 1966. The building has been cited as "a wonderfully flexible building Its interstitial floors and separate office units have made the process of renovation, undertaken at 3-year intervals, relatively easy. However, some critics suggest its construction was excessively costly. (17)

4.3.2. Making Flexibility a Design Goal

Experience with various facility types demonstrates that flexibility or adaptability to change, no matter how it is achieved, is a valuable characteristic that helps delay or avoid obsolescence. (18) Making flexibility—an ability to readily accommodate changed uses, more intense uses, and new service systems—an explicit design goal can assure that the resulting facility is better suited to accommodate future programmatic changes or operational modifications.

4.3.3. Adopting Details That Enhance Flexibility

The details of each facility's design will be established within the context of the facility's life-cycle economics. Nevertheless, as learned from experience in cases such as those cited already, certain design details clearly have demonstrated their value as tools for avoiding obsolescence by enhancing flexibility or adaptability. Past experience also suggests that new materials and products are likely to reduce the relative costs of these details in the future, making their use increasingly advantageous. These design details fall into several broad strategic categories.

4.3.3.1 Unconstrained Interior Space.

Constraints on interior space expansion may be imposed by structural or service (e.g., mechanical, electrical, and/or telecommunications) subsystems or by site characteristics. Provision of large, column-free areas gives maximum flexibility in moving partitions, and 24- to 30-foot column spacing continue to provide such areas without excessive increases in structural costs. Indeed, specialized users' needs, combined with increasingly economical higher-strength materials, often make use of longer clear spans (e.g., 40 feet) practical. Providing areas with increased floor load capacities also enhance responsiveness to changes in functional relationships within the user's organization. Assuring that exterior walls of those areas that may need expansion remain free of site obstructions similarly eases future change.

4.3.3.2 Accessible Service Areas.

Segregation of services from user-occupied space reduces constraint on the user space but, more importantly, facilitates modification and updating of services. Raised access flooring and interstitial ceiling space are becoming routine design features of even small buildings. Floor-to-floor distances of 15 to 16 feet are typical to accommodate this space. Clustering services into uncrowned service and mechanical bays or "canyons," particularly on the building periphery or along concentrated spines, facilitates access and minimizes conflict with interior space partitioning. Access to switches and other control devices for telecommunications, HVAC, electrical, and lighting subsystems is pivotal to the ability to change these subsystems as new technology is introduced. In general, organized plans for utility locations are needed to make accessible service areas fully effective.

4.3.3.3 Modularity.

Separation of major user areas into zones served by independent mechanical (e.g., chillers and blowers) and electrical (e.g., transformers and control panels) components facilitates equipment updating and modification. It also permits greater control in heating or cooling and lighting of the building. Modularity of plumbing elements can produce similar benefits in laboratories or other facilities where plumbing is a major investment and subject to rapid change. Changeable, movable, and demountable enclosure and partitioning systems, finding application in a broadening range of building types, enhance this modularity. New developments in power supplies (e.g., fuel cells), telecommunications (e.g., localized cellular systems), and HVAC control technology (e.g., personalized and wireless digital controls) may make modularity easier to achieve in the future. (20)

4.3.3.4 Shell Space.

Allowing for expansion by constructing "extra" structure, foundation, and unfinished enclosed space increases initial cost but offers substantial reductions in life-cycle costs of obsolescence. Few design elements highlight so clearly the design tradeoffs to be made between present and future costs. However, this approach conflicts with traditional facilities budgeting and procurement, which focus on first cost alone, preventing the effective consideration of these tradeoffs by dividing management responsibility. (21)

4.4. Actions In Maintenance

Management action to avoid or delay obsolescence becomes practically important in the facilities operations and maintenance stages of the life cycle. In these stages the owner and user can act to identify external changes that may signal the onset of obsolescence, while at the same time operating and maintaining the facility to achieve performance according to design intent.

4.5 Post occupancy Evaluation in Facility Management

Post occupancy evaluations (POE) can help in both delaying obsolescence and extending an existing building's service life, when this after-the-fact assessment is used to make adaptations in the facility or its operations. Georgetown University, for example, uses a "Facility Survey" to track the expected life of building systems as well as the schedule and estimated costs of anticipated replacement. In another case, the H.E. Butt Grocery Company in San Antonio has established a POE process involving interviews, questionnaires, analysis of work records, and visits to employee work spaces to support reprogramming of the company's headquarters facility at intervals of about 5 years. (22).

The CERL is working to develop the concept of a Building Performance Interaction Model that would define, for office facilities, the optimal relationships among thermal comfort, lighting, acoustics, air quality, and spatial configuration. Such a model, used as a basis for POE, would facilitate comprehensive development of office environment "report-cards," which could be used to educate users and managers about how to achieve performance approaching the optimum from their facilities. These report-card evaluations could serve as early warnings of changes that may lead to obsolescence. The goal is to devise a self-reporting survey instrument that users would complete, and that would partially or entirely avoid the need for experts in preparing these report cards.

4.6. Adapting for Reuse

When the "fit" between facility and user deteriorates, changing the facility's use often is a reasonable strategy for dealing with this type of obsolescence. This "adaptive reuse" of obsolete structures has become increasingly popular in the United States, particularly where facilities have some historic value. Taking a structure whose service life has been exhausted and giving it a new function is one of the most dramatic responses to obsolescence. Although few cases approach the scope of architect Renzo Piano's proposed reuse of the 1925 Lingotto Fiat factory (a projected-mixed-use facility combining commercial, industrial, and educational institutions), earlier occupancy and savings on reuse of sound and current components of the structure are among the factors that make this strategy appealing. (23) Conversion of an old grocery store into an outpatient medical centre in Phoenix, for example, involved alterations to facades, and interiors, and to mechanical, lighting, and electrical components, as well as the addition of a sprinkler system, yet it was estimated to have saved more than $200,000 and was occupied 6 months sooner than a new structure could have been (Commercial Renovation, 1988). A study of Michigan factories concluded that the these facilities could be redirected and renewed for as little as one-tenth the cost of new construction, and such major corporations as Burroughs and General Electric have garnered praise for successful adaptive reuse of their obsolete buildings. (24) Obviously, adaptive reuse, to be viable, requires that an appropriate new use for the facility be found. As a matter of public policy, tax incentives may be used to enhance the viability of a broader range of alternative uses. However, sometimes facility location and the possible presence of hazardous materials may limit the appeal of this approach to accommodating change.

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CHAPTER FIVE:

FLEXIBILITY A KEY ISSUE IN PLANNING FOR CHANGE IN LABORATORY DESIGN

The central idea of the chapter centres on the inclusion of a potential for change and uncertainty and subsequently to incorporate unpredictability and diversity as intrinsic parameters in the process of laboratory design. It has been argued that the diagnosis of the main instigators of change was an essential key in ‘predicting, not the changes which will affect the life of a given building, but the like hood, rate and degree of changes’. Accordingly, four major causes were identified. These include: I) growth of student numbers, II) change in technology, III) change in the curricula and IV) change in the activity size. Buildings are deceptively complex. At their best, they connect us with the past and represent the greatest legacy for the future. They provide shelter, encourage productivity, embody our culture, and certainly play an important part in life on the planet. In fact, the role of buildings is constantly changing. Buildings today are life support systems, communication and data terminals, centers of education, justice, and community, and so much more. They are incredibly expensive to build and maintain and must constantly be adjusted to function effectively over their life cycle. The economics of building has become as complex as its design.

5.1. Introduction.

‘One of the most remarkable developments in the 20th century is the extension of the scope of scientific discovery’. **(1)** Through this ‘explosive growth of science and technology has generated’ important developments in terms of scientific laboratories provision, yet, argues the New Scientific laboratory design has not kept pace with laboratory activity’**.(2)** Motives claimed to be at the heart of this ‘malaise’ are twofold. The first is that ‘the expertise available in the design and construction of laboratories is not shared’. **(3)** The second is the lack of an architect-users dialectic which stems in the main from the architect’s inability ‘to define, and apply the kind of knowledge needed for good design and good building’. (4)

In addition, as scientists’ needs continue to change rapidly laboratory design moves into an intricate and highly specialised field. This, besides emphasising the urgency of a stringent attention over complex relationships between the various forces involved, highlights that ‘if investment in laboratory buildings is to offer the optimum return, flexibility and adaptability must be central to their design and use’**.(5)**

This article therefore attempts first to outline the prime causes implicated in the occurrence of change in science laboratory activity. Second, to emphasis the magnitude of the task of incorporating a potential for change in the general design strategy of laboratory building in order to maintain the ability of the users to use the facility in an optimum way.
Finally, to examine current approaches whereby to mitigate the effects of change upon laboratory buildings.

5.2. <u>Definition and Concepts.</u>

Undeniably one can understand the meaning of a concept in two discernible ways. One is through the Dictionary meaning, the other is to take the contextual or physical meaning. Accordingly, the Oxford dictionary whilst defining flexibility as ‘the quality of being flexible’ refers to adaptability as ‘the process of modifying so as to suit new conditions’**.(6)** This is to say that the former concept implies the inclusion of change whereas the latter indicates ‘the power of adapting’ or ‘of being adapted’.(7) In the context of architectural design a myriad of studies investigated these concepts in an attempt I) to discern differences in the meanings embodied in these concepts, II) to formulate ways of achieving them through physical design and III) to postulate the extent of the relationship between flexibility or adaptability and change in activity. In this respect, Whyte has identified flexibility as the aptitude ‘to provide for the simultaneous existence of order (or stability) and disorder (or diversity, randomness and change)’ and thus establishing a reconciliation between conflicting polarities.(8) A similar connotation was put forward by Habraken in his theory of mass housing. The key to this theory is the ‘Support’ concept which refers to the hierarchical organisation of sub-systems. Its major hallmark is the separation of the structural support function from the function of portioning, creating as a result, as noted to by Van Doesburg, an open plan which will be subdivided according to users particular requirements**.(9)(10)**

Lynch’s idea of flexibility suggests two routes. One ‘which operates in the present’ is to widen the individual’s choice by providing a broad spectrum of alternatives (for instance a large house with numerous rooms) while involving him in shaping his own physical environment. In Lynch’s terms this is referred to as a ‘plastic environment’. **(11)** However, equating flexibility, as identified above, with the present, while neglecting the possibility of future changes, appears rather short-sighted. Lynch’s second meaning of flexibility calls for a ‘generalised adjustability of an environment of artefact, with minimum effort, to future changes of use’**. (12)** He states that ‘this might best be called adaptability’**. (13**) Although the locution ‘with minimum effort’ is debatable, as Al-Nijaidi argues, it brings to light the idea that the environment must be designed to give opportunity to the users to adjust their environment as their requirements change. Along the same lines is Moharram's definition of flexibility as 'the tendency to change in order to suit new requirements in use'.(14) To consolidate further these views is Fawcett's interpretation of adaptability as 'the ability to maintain compatibility as the activities change'**.(15)**

It therefore could be induced from the above explanations, that i) a schism between the meanings of flexibility or adaptability is by no means universally acceptable and ii) the essence of both flexibility or adaptability, while centring around the quality of an 'object' subject to change, deals with a situation that embodies a degree of uncertainty and unpredictability.

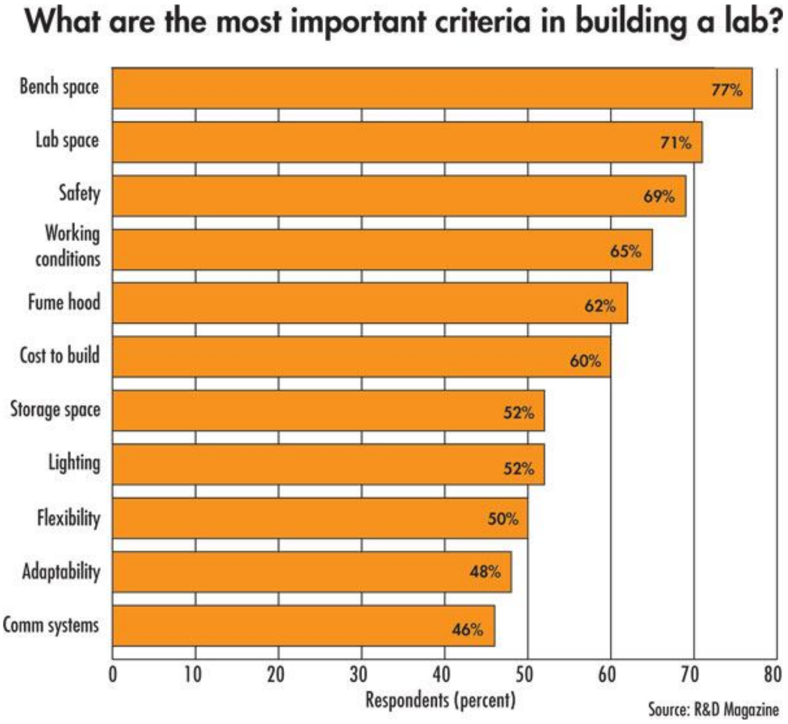
5.3. The Problem of Change.

Change has become one of the most stringing features of modern societies. It has affected almost all parts connected with human affairs. Heath stressed that 'the period of social and technical change is now shorted, often considerably shorter than the life of buildings'. **(16)** However, the recognition that 'structures housing the activities in most rapid flux (universities, laboratories, hospitals & offices) are in constant turmoil of destruction and change' **(17)** emerged in the main from studies by Cowan, Weeks, E. Jones and the Laboratories Investigations Unit Team. (**18) (19) (20) (21)** the array of these investigations generated the most authorative statements about the topic of change. These studies, which aimed at describing and noting the extent of change in relation to the two essential components of the built environment (space and activity) over time have i) demonstrated that buildings grow, change and become obsolete rapidly, ii) manifested the magnitude of incorporating a potential for change in the provision process of an activity and iii) suggested that one major criteria with which to scan the activity-space interface is that of the state of fit. This concept was further investigated by Nutt and Sears who developed a comprehensive conceptual model which combines both the 'objective' and the 'subjective' approaches, as defined in their article on 'functional obsolescence'**.(22)**

The first approach centres around the physical, the financial, the environmental and the functional attributes of obsolescence, while the second involves the users' satisfaction in terms of tenancy, rent and aesthetic qualities of the building**.(23) (24) (25) (26) (27)**

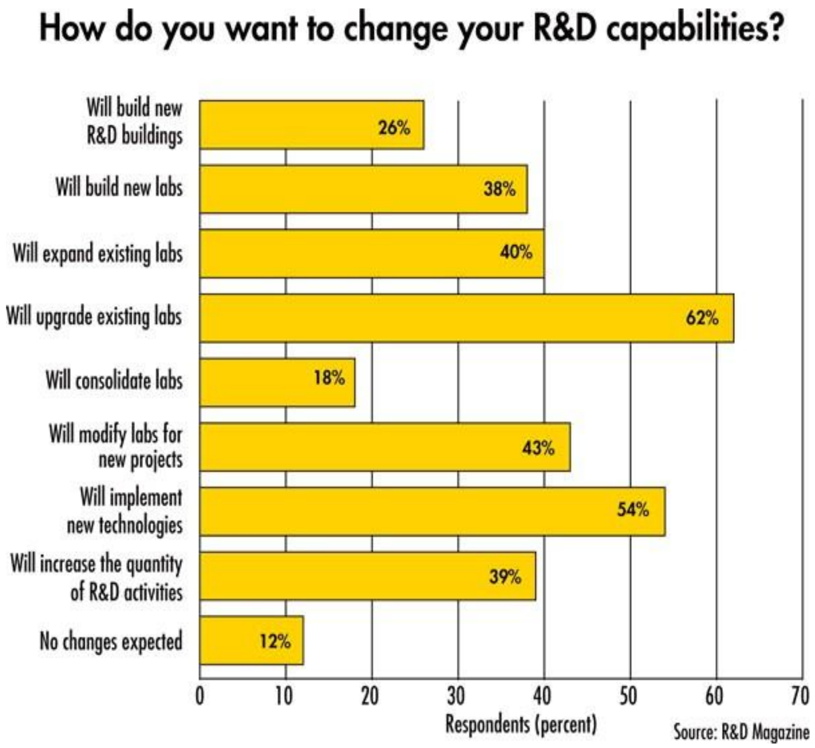
The significance of the inquiry lies in pairing the extent of misfit to both the degree of tolerance of the activity system and the adaptability potential of the physical system. Further, the study also asserts that 'many changes to items of the built stock are irreversible or are at least very costly to reserve', whilst changes within the activity system could be 'reversible to a degree'.**(28)(29)** Correlatively, it therefore appears that the probability of changes in an activity system is higher than in a physical system. Figure 3A and Figure 3B from the Research and development agency set down below shows clearly these concerns.

Table 5.3.1



Source: R&D Magazine 2008

Table 5.3.2



Source: R&D Magazine 2008

Notwithstanding this inquiry, designers when confronted with the issue of change often sought their source of inspiration and guidance from their own experiences. Yet, a review of the available relevant literature suggests that in seeking the operationalisation of ideas dealing with the topic of change, it is essential to formulate the major causes of change in accordance with the nature of the organisation dealt with. This is, as Health argues, ‘not to predict the changes that will affect the life of a given building, but the likelihood, rate and degree of such changes’. **(30)**

Implicitly, the occurrence of change is bound to be due to a number of factors. It is further postulated that ‘it is the change in such factors that constitute the main causes of change in an individual activity demand over time’. **(31)** Attempts to describe the various causal factors suggest that these are closely connected to the nature of the activity. **(32)** Accordingly, the DfES paper entitled ‘School for the Future’, ‘Which describes a philosophy of laboratory design intended to cope with the changing requirements of scientific and technological activity’, taken together with some other studies in the subject showed four dominant forces shaping changes in university science teaching laboratories. These are first, the growth of student numbers in the fields of science and technology teaching, second change in technology, third change in the curricula and lastly change in the size of the activity. **(33) (34) (35)**

3.1. The Growth of Student Numbers.

It is a truism to claim from a metaphysical stand point that growth is a natural and intrinsic characteristic of the global evolutionary process that control 'things'. Though its significance in the field of architectural design is indisputable, the extent of its relevance is however questionable since extrapolating meanings surrounding the process of growth through an analogical presentation of matter could be misleading, as Cowan pointed out**.(36)** He (Cowan) further observed that i) unlike the mitotic mechanism that regulates tissue growth, 'buildings grow by accretion', appending external parts to an existing core and ii) by contrast to the 'natural' occurrence of growth in living organism and some minerals, the growth phenomenon in the case of buildings eventuates as a result of 'human action'**.(37)**

Medawar argued that one prime variable contributing to the genesis of growth in human activities is the increase in the size of the social group dealt with**. (38)**
The L.I.U's (now called the DfSE) investigation at the University of Surrey showed that the establishment of new premises subsequent to an increase in student population led to changes within parts of the existing facilities. These changes were i) 'changes in use of existing laboratories' in terms of benching, storage, some services and part of the structure and ii) annexation and adaptation of space formerly assigned for other purpose. The study also observed that 'shunting' was the prevailing procedure whereby changes were brought about**. (40)** It therefore follows that, while it can be suggested that growth in the size of the social group could enhance the likelihood of changes in the fabric within which it is housed, it can equally be contented that growth in the group size generates the need for supplementary space. The provision of this extra space takes two forms; either the erection of new premises (growth by accretion) or the annexing and converting of spaces formerly used by another department. The former is referred to by both Cowan and Nicholson as 'real growth' or 'increase in floor space'**. (41)**

5.3.2. Change in Technology.

'It is widely and ritually repeated that a world of technology is a world of change'. **(42)** This implies that there exists an inherent impetus towards change in the use of technology. It is further argued that 'one of the most common characteristics of technology is that it brings about changes in physical nature'. **(43)**

A major factor that has enable new educational ideas to flourish are the use of technological monitoring devices e.g. closed circuit T.V, computers, and audio-visual materials. This is particularly true in science laboratories where the nature of scientific inquiry, which involves 'observing, measuring and building explanatory models to make sense of findings', has shown over the last two decades an increasing reliance on a myriad of mechanical devices and electronic equipment so as to cope with the development of new experimental techniques. **(44) (45)** The use of such tools has however led to a dilemma. Though technological hardware is considered vital to laboratory instruction, Weeks argued that it has contributed in developing a 'finite geometry' which could impede further developments of the organisation. **(46)**

The acuteness of the issue takes an extra dimension since change in technology seems to occur in an unknown direction and at an alarming rate. Studies surrounding the nature of the impetus for innovation in laboratory equipment stimulated some thoughts about the causes of such change. The first is that the technology in place might be surpassed by the emergence of a new alternative which could i) widen the spectrum of use, ii) enhance the level of efficiency and iii) be cost effective in the long run. This can be exemplified by the L.I.U's hardware system (lab kit) which acknowledges current and predicated patterns of use. The second explanation centres around the fact that the occurrence of change in the performed activity (e.g. in its size and character), as a result of a new academic pattern within the institution, could i) limit the usefulness of some of the available facilities and ii) engender changes in some aspects of space such as the area and the height. **(47) (48) (49)**

The final consideration, as Duffy and Worthington pointed out, relates to the well of the organisation to incorporate novel ideas within its structures. **(50)**

To sum up, it could be suggested that if a dynamic science laboratory 'milieu' is to be provided, it seems best to formulate a positive prescription for its design. This could be based on planning for change and thus acknowledge that change in technology seems to be accompanied by a corresponding change in the laboratory physical environment. **(51)(52)**

5.3.3. Change in the Curricula.

Gone are the times when the 'Trivium' and the 'Quardrivium' concepts prevailed as the legitimate gates to higher education courses. The Gargantuan progress of science during the course of the current century has generated the proliferation of all kind of courses which 'range from the most pure to the most applied'**.(53**) Furthermore, the dividing line that once regulated the disciplines' boundaries has become less distinct as overlapping between them increases. Musgrove best described the above situation when wrote in the A.J in January 1965 he observed that, electronics has revolutionised techniques in every discipline to the extent that physics are to be found in almost every laboratory, no matter what named discipline it houses. **(54)**

These developments were reflected by changes in both the content and the internal structures of the disciplines. This in turn produced a growing tendency towards a multi-disciplinary use of science teaching laboratories**.(55) (56)** The operationalisation, however, of such a new educational concept gave rise to important requisites. Primarily, it has made the supply of a 'broader spectrum of facilities at any one teaching station' important since every discipline, though its requirements are substantially akin to some other ones, has nevertheless its own physical existence as well as theory, concepts, contents and methodologies**.(57) (58)**

Branton and Drake's study entitled 'Developing a Range of Adaptable Furniture and Services for Laboratories', which stems from an investigation carried out at the University of Surrey, observed that 'with multi-disciplinary use some changes took place from term to term' endorsing therefore the case for both flexibility and adaptability in use. The study noted two kinds of change: i) changes in the pattern of use e.g. changes in group work and ii) changes in some physical and environmental aspects of the shell e.g. adjustment to working areas, services, equipment and furniture**.(59)** Additionally, the L.I.U paper No.9 argued that though the inclusion of a diversity of scientific tasks into a laboratory called for a much less stereotyped pattern of courses, it has contributed to the intricacy of estimating the number of students involved in a particular discipline**.(60)** It ensues therefore that change in the curricula appears to have subsequent repercussions upon the laboratory environment, thus suggesting that the design of science laboratories could be best upon its potential for flexibility and adaptability, in order to fit the eventuality of change

5.3.4. Change in the Activity Size.

A significant characteristic recognised to influence the activity-space relationship is connected with the activity size, to the extent that it is further claimed that occurrence of change in the activity's size could engender a reciprocal spatial variation**.(61)** Inquests surrounding this claim reckon that scanning the criteria by means of which to measure the size of an activity is a prime agent in seeking explanations of the extent of the congruence between the physical nature of the activity and its demand for space. **(62)** In this respect, criteria that set out the size of an activity include i) the total number of people involved in the institution and ii) the inherent 'texture' of the activity within an institution, for example the number of hours taught in laboratories or the number of beds tended in hospitals. **(63)(64)**

The applicability of these criteria is closely tied to the context within which the impact of change in an activity's size is to be explored since the variability of institutions characteristics implies a variability of units of measure. In some cases only the first criterion (i.e. number of people involved) is used to measure the relationship indicated above whilst in others a combination of both i) and ii) may be necessary. Exemplifying the former case in the study conducted by Duffy and Worthington in the field of office buildings. Their investigation released evidence that fluctuations in the number of personal were followed by similar fluctuations in the area housing them. The same affinity has been found by Cowan and Sears, Whose inquiry about how an advertising agency accommodated change over a period of ten years showed that increase in the number of people involved resulted in a corresponding increase in the area that housed them. **(65)**

As far as laboratories are concerned, inquiries by the L.I.U group which employed both criteria i.e. that of the number of people and the of the intensity of use or the number of hours taught, demonstrated that increase in the size of an activity induced a parallel increase in the area used **. (66)**

Though it appears that there exists a pattern of association linking increase in the size of an activity to increase its spatial requirements can seldom be attributed to a single isolated factor. More often it is the combination of several factors which produces changes in the laboratory's activity. Thus a cognitive attempt which seeks the explanation and identification of potential causes of change in the context of laboratory design could best proceed through a 'holistic' approach. Popper argued that the array of causes involved can not be regarded as the mere sum total of the factors dealt with nor it can be seen as the mere sum total of the merely individual relationships existing at any moment between those forces and the environment**. (67)** Change in the activity's size could be inherent to the incorporation of the concept of multi-disciplinary use, which in turn stems from the restructuring of the curricula. It could occur as a result of inter-alias such as the emergence of new technology or be consequent upon a growth in student numbers. Any of these cases could imply a need to erect new premises or expand existing ones to cope with the new size of the activity. **(68)(69)**

5.4. Design Strategies for Coping With Change.

Both research into and practical experience of laboratory design has brought to notice an interesting conflict between the life span of buildings and the effects of growth and change upon them**.(70)** Heath argued that taking into account the magnitude of change has at present become an established key to architectural design**. (71)** Moreover, to design, as Jones puts it, 'is no longer to increase the stability of the man-made world: it is to alter, for good or ill, things that determine the course of its development'**. (72)**

Accordingly, the resurgence of interest in the field of laboratory design, besides attending to the exigency to enhance the quality of health, safety and convenience requirements, highlighted the urgency to describe and predict the problems caused by change on buildings designers have come up with a diversity of ideas and proposals. These endeavours, noted in the L.I.U's study at the University of Surrey and in the Saint Michael's Academy's report, include improvisations in the use of laboratories, building extensions, conversions and minor changes to partitions, services and finishes. These however are not considered design strategies as such but rather as design aids to alleviate the effects of change on buildings. The most recognised and current design strategies, identified by Heath, are flexibility, the long-life loose-fit to which the attribute of low energy is now associated, and scrapping. Each of these three strategies has its own contextual use and each is discussed separately in the forgoing paragraphs.

5.4.1. Flexibility.

It has been argued throughout these lines that laboratory design is controlled by an array of design variables that are subject to change. These changes are often unpredictable, and in many cases result in a premature functional obsolescence of the premises. Although there is still controversy surrounding the inclusion of flexibility in laboratory design from its initial stages due to its expense, its incorporation, has become a preponderant key in planning for change**.(73)(74)**

Various approaches have been put forward by designers to provide flexibility in the laboratory environment. These, as pointed out by Clynes and Branton, include i) laying out laboratories on a modular repetitive bay, ii) provision of services on a regular grid, iii) developing the structure of the building to take a wide range of alternative partition layouts, and iv) choosing or designing unit laboratory furniture so that it can be added to, subtracted or rearranged as required**.(75)** They further argued that while in items (i) and (ii) the stress is on flexibility.(**76**) The L.I.U paper number one argued that these 'tactics (as alluded to in the paper) can be successful in making a laboratory more amenable to change but in practice there are difficulties'.**(77)** For instance the flexibility of structure embodied in items (i), (ii)and (iii), which involves the concept of 'over-provision', is argued to be accompanied by an investment beyond the capital cost initially assigned to the building. The other difficulty, already discussed, is that of some environmental problems such as acoustics due to the limitations often associated with the use of movable partitions.

In the quest to bridge the shortcomings of these design procedures a number of designers developed new design strategies to achieve flexibility. There emerged various concepts, namely: the 'shell' in laboratories, the 'hierarchical organisation' or the 'support' concept in housing, the 'hard-soft' in hospitals and the 'shell-scenery' in offices buildings**.(78)(79)(80)(81)** Regardless of the institution within which these concepts are applied all centre around the distinction between those parts that are 'time-dependant' and those that are 'time-independent'. Arguably, there is no part of a building that is not time dependent; what is meant by the above phrases is the identification of those parts of the building that have been found to last longer than others, and are thus less subject to change. Despite the existence of a common core, concepts applicable to problems of one type of institution can not be applied to elucidate those in order institutions since, as AL-Nijaidi argued, the problem of change varies from one instance to another**.(82)**

The 'shell' concept is the basis of a key idea in laboratory design in which a hierarchical relationship is established between those parts of the building termed basic and regarded as long life ones (e.g. enclosure, structure and some services) and those parts identified as supplementary and regarded as short-life ones (e.g. partitions and furniture). The L.I.U report entitled 'An Approach to Laboratory Building' emphasised that the form and character of the shell stem from a number of criteria which are: i) overall area, ii) range of ceiling heights and floor loads, and iii) quantum of natural illumination needed. **(83)**

The practicality of the concept developed by the L.I.U team to find out to what extent a shell can accommodate 'all the basic scientific disciplines' and 'how far a distinction must be made between the physical sciences with mainly dry services on the one hand, and the chemical and biological sciences with mainly wet services on the other' **(84)**, has yet to be evaluated. However, it is significant to note that studies about the concept suggest that the principle of separation of a building system into physically independent sub-systems reduces the degree to which these elements act as a potential constraint to flexibility.**(85)**

5.4.2. The Long-Life Loose-Fit Concept.

The impetus that grave rise to the concept of long-life loose-fit sprang initially from studies carried out by Cowan and Nicholson in the field of hospitals and health care facilities**.(86)(87)** The concept refers to the relationship between certain physical attributes of the space and the activity it houses. This relationship, as argued by Gordon and Weeks, centres around the accommodation of change, and consists in bridging the gap between the long life of the structure and the short life of the activities they house. **(88)** Ideas for implementation of this concept pointed out two discernible approaches. One is 'over-provision' (T. Heath and the L.I.U team) or 'over-capacity' (C. Alexander), the other is neutrality (Al-Nijaidi) or 'indeterminate' (R. Oxman).

5.4.2.1. Over-Provision.

This first approach is based upon the idea of providing extra resources in the building than are initially required. This concept involves physical attributes (e.g. area and structure) as well as some aspects of services. The main argument for this procedure, as Al-Nijaidi points out, 'centres around the assumption that an extra provision would prove useful if the requirements of activities housed in rooms increase over time'**.(89)** The practicality of such a procedure remained however largely untested, for two main reasons. First, as argued by Lynch, Heath, L.I.U and Lawson, over-provision generally engenders high operating costs. **(90)(91)(92)(93)** Second, over-provision could only be justifiable if future requirements proved similar to the predicted requirements. Such a condition, Lynch argued, is seldom met and thus 'the whole exercise could prove unfounded'. **(94)(95**) Therefore it could be suggested that looseness of fit could prove unsatisfactory if over-provision is adopted as the ultimate procedure with which to counter the problems of change and uncertainty.

5.4.2.2. Neutrality.

The second approach to achieve the concept of long-life loose-fit stems from a general idea that the design should be 'as non-committal as possible', as Lawson advocates**.(96)** This idea goes further to refute the functionalist approach which failed to recognise the dynamism of change specific to the life of the building and the activity it houses. It made clearer the case for 'neutral' or 'indeterminate' buildings**.(97)** By opposition to a concept of a lasting design, neutrality developed as a design paradigm which attempted to incorporate both diversity and unpredictability as essential parameters of design in order to create buildings capable of responding open-ended to change and uncertainty.

The keys to achieving neutrality, as Al-Nijaidi argues, are uniformity and variety**.(98)** These two opposing concepts put to use to achieve neutrality involve either increasing or decreasing similarity between the various components of the building. Whilst uniformity embodies the notion of ‘uniformity of room sizes’, variety, on the other hand, implies the reserve**.(99)** The argument for advocating a maximum of similarity revolves around two major axes. The first, as Weeks argued, is to establish the limits of required room sizes and subsequently to provide room sizes which can accommodate a number of ‘duffle coat’.(100) Its application calls for a combination of an extensible pattern of communication with the provision of a set of room sizes which relate to a known range of activity sizes. The second is associated with the standardisation of some components of the hardware of the building, e.g. structural components and services.

The crux of variety, on the other hand, consists in ‘the separation of the structural function from the function of partitioning’ leaving therefore the opportunity to the users to subdivide the space according to their requirements. Although this procedure has been found to increase the potential for flexibility in the short term, Lynch observed that the exercise could prove vain in the long run. He further asserts that ‘there must be many present variations which will never pay off when the unknown future change arrives; then the solution becomes a very wasteful one’.(**101)** Another difficulty, emphasised by Aylward, is that a fundamental condition to maintain the provision of variety is that activities and space must have long periods of misfit**.(102)** Hence while it is suggested that neutrality can be achieved by two distinct approaches, conceptually the reverse of each other (uniformity calls for maximising similarity whereas variety relate to minimising it), the first concept (uniformity) seems to have found more acceptance than the second (variety).

5.4.3. Scrapping.

The third response to uncertainty and change, and most controversial of all three design approaches, is scrapping, also called ‘throw-away design’**.(103)**This concept refers generally to the readiness of a designed object ‘… to ease of demolition and re-use of demolished materials and equipment’**.(104)** Its main argument, as presented by Alward, is based on the assumption that if obsolescence is built in, then the idea of a temporary structure either in terms of its life span or its use span could prove beneficial**.(105)** The key to this design paradigm is the use of temporary structures or ‘temporary hutted accommodation’ as described by the L.I.U. The feasibility of such an approach is open to question. The L.I.U argued that it is liable to create low physical standards. **(106)** Schulitz noted the problems implicit in using such an approach in the case of mega scale buildings such as universities, hospitals, and airports. He further claimed that it would be a real forfeit ‘to build large scale structures with an economically justifiable short life span since heavy structural parts required for stability and safety are inevitably long-lasting', **(107)** thus rendering permanent those elements of the building which were initially considered temporary. One further criticism is that put forward by Lawson, who argued that 'this consumerist approach [scrapping] is not only wasteful of resources but also leads to short-lived goods of continually reduced quality and thus the option of replacing outdated goods turns into a basic necessity'**.(108)**

Thus though scrapping has been suggested as a potential way to respond to change and uncertainty, the arguments of its advocates remained largely unsound due in the main to the serious limitations implicit in the essence of the concept.

5.5. Summary

As laboratory design has become more complex and as the rate of sociotechnic development accelerates 'the construction of predetermined unchangeable buildings become' more and more questionable**.(109)** The central idea of the article centres around the inclusion of a potential for change and uncertainty and subsequently to incorporate unpredictability and diversity as intrinsic parameters in the process of laboratory design. It has been argued that the diagnosis of the main instigators of change was an essential key in 'predicting, not the changes which will affect the life of a given building, but the likehood, rate and degree of changes'. **(110)** accordingly, four major causes were identified. These include: i) growth of student numbers, ii) change in technology, iii) change in the curricula and iv) change in the activity size.

Three potential design approaches to mitigate the effect of change upon science laboratories were identified. These include: flexibility, long-life loose-fit and scrapping. All three have been found likely to induce high initial costs, and/or subsequent costs. While first two approaches found substantial ground for application the third concept remained largely unsound.

Accordingly, this article scanned succinctly these design concepts, manifested that ideas about flexibility and adaptability tended to suggest that while their main respective objectives centred around the quality of an object subject to change, highlighted uncertainty and unpredictability as important hallmarks of the situation dealt with. It also emerged that the impetus that gave rise to the incorporation of a potential for growth and change arose from the recognition that buildings in most rapid flux, such as universities, laboratories, hospitals and offices, grow, change and become obsolete rapidly.

Finally It has been argued throughout that the resurgence of interest about the subject of laboratory design, to improve health, safety and efficiency standards brought to light the complexity of having to design for the needs of an immediate use and yet having to meet responsively the occurrence of change and growth in the laboratory's activity.

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CHAPITRE SIX:
ACHIEVING SUSTAINABILITY FOR LABORATORY FACILITIES

SECTION A
CONCEPTUAL TOOLS

6.1 Introduction

Modern higher education facilities provide usable space for laboratories, laboratory support areas, offices, and interactive spaces for formal and informal gatherings. The special equipment and environments required for the interface space/user make these facilities complex and expensive to build and operate. Complying with building codes and considering building standards are part of the architectural programming process. (1) Organizations priorities will set the tone for the incorporation of a performance based measures for the facility. It is important that the facility be able to accommodate changes in use by including flexibility in the original design. However, energy consciousness must not be overlooked in the outset of the design process even though the facility may plan for larger system capacity in the future. Architectural arrangements that provide laboratory isolation can result in energy efficiency benefits by using a design concept that includes modular degrees of isolation for the required controlled environments. Linder noted that, the modular laboratory provides an opportunity to arrange the environmental conditioning systems efficiently. Utility service coordination, by providing orderly pathways and routing, will reduce energy use by reshuffling their layout and configuration. Mini environments can confine energy-intense environments to small volumes. (2)

6.2. Laboratory type According to Activity

6.2.1. Chemistry Laboratories

Chemistry laboratories tend to break down into the following generic spaces: organic chemistry, inorganic chemistry, physical chemistry and analytical chemistry.

6.2.2. Biosciences Laboratories

These laboratories are distinguished by the support space that is required for each laboratory or group of laboratories.

In most ceases, such support space houses: shared equipment, such as centrifuges, freezers, or gas chromatographs; spaces that need to be separated and enclosed for environmental reasons, such as cold rooms, warm rooms or containment laboratories; or spaces that house specialized functions, such as flow cytometry, tissue culture or autoclaving.

Fume hoods, as well as bio safety cabinets and laminar flow hoods, are used in all areas of bioscience research. Storage for chemicals (solvents and acids) must be provided in accordance with applicable codes. (3)

6.2.3. Physical Sciences Laboratories

Physical science laboratories are distinguished from other types of laboratories in a number of ways. First, there is only a small amount of built-in furniture. Second, there is abundance and a variety of electrical power. This, of course, is due to the fact that in most physical sciences research labs the floor space is occupied by an array of mind-boggling apparatus and instrumentation, both home-built and store bought. Almost all of this equipment requires power of varying voltage and amperage... Power and piped services are usually provided from an overhead suspended service carrier.

The scientists will then build the experiment within the empty floor space, connect to the overhead services and provide additional work surfaces with movable tables that can easily be rearranged.(4)

Table 6.2.3. **Physical Sciences Laboratories**

Source: [Lindner, 1990]

6.3. Design Flexibility

6.3.1. Energy Efficiency and Design Flexibility

In the design process, the energy engineer is most likely to encounter a desire for adjustability and expandability of the laboratory's energy-using systems, notably its environmental conditioning (HVAC) system. Planning for facility flexibility, in the form of future expansion by the design group, will push the sizing of these systems to larger capacities. To accommodate these capacities it is important to apply a "right-sizing" systems approach. This will ensure that the near-term system usage will be efficient. (5)

6.3.2. Adjustability

The second level of a laboratory's flexibility is its ability to adjust and redirect function with minimum disruption of operations. Trades personnel, using common hand tools, may be required to remove or install new equipment and attach to building services and utilities in a reasonable amount of time. Examples of adjustments include adding or removing sections of lab counter tops, rearranging casework and shelving, and adding or removing a fume hood or a biological safety cabinet. When a fume hood or a biological safety cabinet that has dedicated exhaust is changed, adjustments to the entire facility's HVAC balance and EMCS will be required to preserve user safety and comfort. Fume hood removal or installation and casework changes must take place without impacting adjoining lab operations or disrupting building services. (6)

6.3.3 Expandability

The third level of a laboratory's flexibility is its capacity for renovations that reassemble interchangeable subcomponents into new spatial configurations or new functional assemblies. Products such as system furniture, modular walls, modular utility systems, and modular ceilings can change size, shape, capacity, and location. Expandable modular laboratory components allow for changes in fenestration, interior walls, door placement, HVAC zoning, and utility distribution with the addition, subtraction, and relocation of the modular subcomponents. For instance, a modular ceiling allows the number and or placement of HVAC registers and light fixtures to change. Expandable modular building components allow for changes in the capacity and location of major building elements, such as the mechanical, HVAC, and plumbing services.

Laboratories should be designed to one of the above flexibility levels. In most cases flexibility options are mixed, based on the future needs of the facility. (7)

6.3.4. Operational classifications

An operational classification matrix includes the functional distinctions described above as well as process complexity, which reflects the project mix and the procedure mix in the laboratory. The project mix is an indicator of the variety of the research conducted in the laboratory. The procedure mix is the number of experimental or analytical protocols used in a single type of research in the laboratory. This "matrix" of operational and physical similarities then describes what well-planned laboratories have in common. (8)

6.4. Understand Barriers

The goal of the energy-efficient design process is to have considered all energy-efficiency options and incorporate the best into the final design. However, numerous real and perceived barriers exist, such as higher than normal first costs and out-of-date design standards. Creating an energy-efficient laboratory design requires an understanding of and a willingness to surmount these barriers; with persistence, an energy engineer can optimize system performance and individual components to produce an effective, integrated, energy-efficient design. A list of barriers is given below. (9)

6.5. Conflicts among flexibility types

Flexibility in the laboratory design offers the chance to deal with organizational change effectively. However, conflicts may occur during planning that can render flexibility choices useless unless the conflicts are resolved. For the energy engineer, those conflicts fall into two categories: physical and safety. (10)

6.4.1 Physical Conflicts

A singular flexibility type may be selected for a lab; problems may result from attempts to blend flexibility types. These problems develop when the interaction, assembly arrangement, and fit tolerance of the building systems are at odds with one another. Assembly methods must allow the altered system to be relocated or reconfigured quickly when it must work within other system elements that are slow and difficult to change (11)

6.4.2 Safety Conflicts

The energy engineer must consider potential safety conflicts that will arise from flexible laboratory designs. Although easily relocated and convertible components like hoods and wall systems give flexibility, changes should not become easy enough for individual users to do on their own. There can never be enough built-in safety controls to ensure proper application. (12)

6.5. Flexibility and planning

Flexibility is often substituted for comprehensive planning. If time is available in the design process, the energy engineer should propose scenarios describing how the progress of research in the lab space can lead to renovation, major or minor. Alternatively, scientists who will use the laboratory can describe how the progress of their research projects will create new design requirements in the space, or how their past work evolved to require new changes in existing lab spaces. All of these scenarios should include the best projections of the likely changes through the life of the facility. (13)

New facilities will be flexible, more heavily equipped, more sterile, more secure, and more expensive and they will be operated by more highly skilled and educated personnel. The challenge to laboratory facility designers is to build a strong knowledge base of general science, become informed about the successes and failures of today's energy-efficient laboratories, assist in the development and analysis of the clients' laboratory performance requirements, and synthesize this information into a design solution. (14)

As Ruys cautioned righteously though we ought to

…"keep in mind that on this subject, the last word is: there is no last word. This is true because lab planning and design are based on the unpredictability of science and technology. Tested and workable solutions are not constants to be applied to the design process. Engineers should review these solutions each time and must update them continuously to help guide the process of providing laboratories that will work efficiently now and in the future on If changes are made by untrained personnel." . (15)

6.6. Laboratory Adjacency

6.6.1. Energy Efficiency and Laboratory Adjacency

Eliminating cross-contamination between laboratories is a primary consideration in designing safe and productive laboratory facilities. Energy efficiency can be accomplished with a design concept that includes modular degrees of isolation for the required controlled environments. Laboratories that contain individual processing rooms can modulate the isolation pressures more accurately, increasing both energy efficiency and safety. By designing the facility with multiple degrees of isolation, several processes can be maintained concurrently. (16)

According to Cooper: "the pace of discovery and the potential hazards of research have dictated that sophisticated mechanical and electrical systems and services are available to create pleasant, productive, and safe environments for scientific inquiry. It is not unusual for the building volume devoted to systems and services to exceed the usable or served spaces". (17)

6.6.2. Support activity integration

Support activities include spaces for special equipment or work tasks that require unique environments such as animal control rooms, tissue culture, or darkrooms. Noisy, vibrating, and high-heat-generating equipment such as freezers and centrifuges are better located slightly remote from the laboratory bench area. Here again, it is not unusual for this laboratory support space to equal or exceed the area of the research laboratories. Laboratory support activities should occur away from the "bench area," but close by.

6.7. Environmental Design Attributes

Laboratories exist to provide the precise environmental conditions required for performing scientific tasks. These conditions require sophisticated, expensive, energy-intensive HVAC systems. Laboratories typically consume 300,000 to 400,000 BTUs per square foot per year or more, six to 10 times the number of BTUs consumed in a typical office building. However, energy consumption and operating costs can be reduced through "right sizing," choosing the most efficient and cost effective combinations of equipment and equipment sizes as well as managing the laboratory load, all to achieve energy efficiency. A comprehensive example of incorporating right-sizing techniques is provided in a report by Wrons (1998) on Sandia National Laboratories' Process and Environmental Technology Laboratory (PETL) located in Albuquerque, New Mexico. Right sizing is an iterative process; although new techniques are developed continuously, the basic elements are: Life-Cycle Cost Analysis and Diversity Analysis. (18)

6.7.1 Life-cycle Cost (LCC) Analysis

Energy intensive environmental conditioning systems have high operational and first costs. Therefore, it is very important to consider the optimum mix of operational and first costs to determine the system's life-cycle cost. Life-cycle cost (LCC) analysis accounts for all costs incurred for the HVAC system from installation through a chosen period of time, usually 20 years. Life-cycle cost analysis is a **"yard stick"** to measure the relative benefits of the choices available to the design team. Estimating the conditioning capacity necessary for a laboratory includes a myriad of choices to determine the laboratory's HVAC system type and size. To make these choices intelligently, the engineer must understand the variability of the laboratory facility's load profile. Airflow rate through the facility is a subject of considerable debate that is primarily driven by the air change rate per hour (ACH) and the design fume hood face velocity. (19)

6.7.2. LCC factors

LCC factors that influence a laboratory's HVAC system design can be broken into three categories: design factors, economic factors, and performance factors. Sometimes other factors must be considered; for example, a functional-use factor may be developed based on efficiency studies of personnel in the operations of different laboratory systems or components. Because laboratory personnel LCCs are very high, the more functional a design or system is, the more LCC savings are possible. An example is the workspace flexibility and reduced costs of space planning that can be afforded by a raised floor system.] (20)

6.7.3. LCC design factors

LCC design factors include: design temperature and humidity; room air-flow rate (air change rate); hood size and number; face velocity; and climate. Other design parameters include laboratory and office support spaces, and the number of fixed-rate exhaust systems per laboratory. All design factors are subject to review, including climate data, e.g., which meteorological year to choose, and design temperature and humidity, e.g., which indoor and outdoor design temperature levels are appropriate. (21)

6.7.3.1. LCC and Adequate Space

Steere (1990) points out the relationship between space for the laboratory's ventilation system and life-cycle costs: Since adequate space for ventilation ductwork and equipment is absolutely crucial for its maintenance, modification and economical operation, the laboratory planner needs to be sure that the budget is adequate and that no last-minute cost cutting is allowed to reduce the size or height of areas needed for the ventilation system. Such changes will increase the life-cycle cost of the building by permanently increasing the difficulty and hazards of servicing the equipment and by decreasing the performance and cost effectiveness of the system. (22)

6.7.3.2 LCC Techniques

Life-cycle cost analysis (LCC) offers project owners and architects techniques to make investment trade-off decisions. To better comprehend LCC techniques, the following concepts must be understood.

- Life: The life expectancy of a building. Does the building need to last 10, 40 or 60 years? This must be considered when establishing project objectives and goals, as it will affect the cost and design of the facility. Factors affecting the determination of a facility's life for calculation purposes are many. They relate to projected ownership, expected use, applicability of depreciation, financing sources and the purpose of the project.

- Cycle: The building's yearly or monthly cycle in terms of operation and maintenance, and its expected cycle for remodelling and replacement.
- Costs: All present and future costs associated with the project projected over the life of the facility. These costs are factored using projected inflation, interest rates and depreciation, and other factors affecting the cost of money in the future.

The energy costs of a laboratory facility can be calculated by examining the energy requirement of outside air flow through the building. In buildings ventilated at eight air changes per hour (ach) and higher, the energy transfer through the building skin is insignificant. It is also present, regardless of whether the mechanical system is constant or variable volume, and can be neglected for comparative studies. (23)

6.7.3.3. LCC Economic Factors

Economic factors are generally more accurately known than the other LCC factors. Economic factors include: present fuel costs for heating and cooling; fuel cost adjustments over the life of the facility; and incremental cost for EEMs, service life, and interest rates. The installed cost of EEMs should be estimated using costs from recent projects in the same region as the facility being designed and a contingency factor should be included to account for future expansion and cost overrun possibilities. Preliminary discussions with construction contractors and vendors should be completed and included in LCC data. (24)

6.7.3.4. VAV Systems

A laboratory-type facility has stringent air-flow requirements to create a safe, constant, controlled environment. Additionally, laboratories have areas where air volume and temperature must be adjusted according to occupancy. In either new designs or retrofits, VAV systems can make HVAC systems operate more efficiently to meet these needs. When a facility is only partially used or occupied during the day, the VAV system has a high, part-load operating efficiency. In order to achieve additional energy savings, the VAV system reduces the average ventilation rate in laboratories when they are unoccupied. (25)

6.7.3.5. LCC Performance Factors

Laboratory performance factors are the most difficult to quantify. This important group includes: HVAC system diversity; laboratory heat gain from process loads; fume hood user energy-efficiency practices; maintenance costs; system failure rate; and heat recovery and free-cooling effectiveness. (26)

6.8. Diversity Analysis

According to Cooper, diversity analysis in a laboratory ventilation system accounts for the fact that not all laboratory spaces or fume hoods are operated at 100 percent, 24 hours per day. The larger the facility, the smaller the probability of simultaneous use of all available capacity. Studies and practical experience have shown that, for large laboratories with many fume hoods, at least 20 to 30 percent are closed or only partially used at any one time. Therefore, HVAC systems can be sized for 70 to 80 percent of peak ventilation capacity. Sizing the HVAC system at 70 percent of peak load decreases operational and first costs, gives better system control, increases system stability, and reduces mechanical space requirements. Taking advantage of diversity is particularly valuable when retrofitting existing facilities where available space is limited. Therefore, it is very important to consider diversity when sizing a large laboratory HVAC system. Small, single-room laboratories should always be sized for full 100 percent capacity without downsizing. (27)

6.8.1. Energy Efficiency and Diversity

Diversity in laboratory design can permit downsizing of equipment, reducing capital and operating costs. The diversity factor is used when considering all of the HVAC system components for the laboratory including: boilers, chillers, cooling towers, pumps, air-handling units, ductwork, heat recovery, and mechanical spaces. Only the equipment supporting the whole facility can take advantage of this diversity. While local diversity may occur in various parts of the facility, the local diversity may differ substantially from the diversity of the whole.

According to Lentz and Smith (1989) report on a "study performed at a large medical research facility in New England" that "demonstrated that the diversified electrical load on that laboratory was between 50% and 55% of the total connected electrical load.” However one must be cautioned not to use this example figure carelessly, since use characteristics will vary with facility character and type. Intuitively, though, it should be obvious that it is very unlikely that all equipment will be needed and operated simultaneously in any but the very smallest facility. (28)

6.9. Modular Design

6.9.1. Energy Efficiency and Modular Design

One of the most important strategies to incorporate flexibility in a laboratory-type facility is to provide modular systems. The main energy-use benefit of the modular research laboratory is the flexibility it provides to arrange the environmental conditioning systems efficiently. The modules can accommodate a wide range of mechanical and electrical systems with a broad variety of energy-efficiency features. These modules can expand incrementally to provide enough physical space for initial use, and for future growth. (29)

Figure 6.9.1. Modular Design

Source: Cooper, 1994

6.9.2. Laboratory Modules

A laboratory module is the three-dimensional planning unit composed of a specific floor space for laboratory work that is repeated throughout the facility. The module is related proportionally to other building systems. Modules are combined and divided into viable units to satisfy the researchers' programmatic needs. They have planned and identified locations for partitions, ceiling and lighting systems, supply and exhaust air systems, plumbing and piping systems, and electric power distribution. The energy engineer should make modular space planning decisions by applying the principles of value engineering. The energy-efficiency considerations in the selection of a planning module include but are not limited to the following aspects:

- access, and internal traffic patterns,
- location of the offices and support spaces,
- location of the hoods,

- accommodation of process equipment, and
- The number of people in the space.
- Laboratory modules are intended to facilitate safe, cost-effective modification of support systems when the inevitable changes to the space occur. The mark of a good laboratory design is that its energy efficiency, safety and economy complement the modular nature of the design. (30)

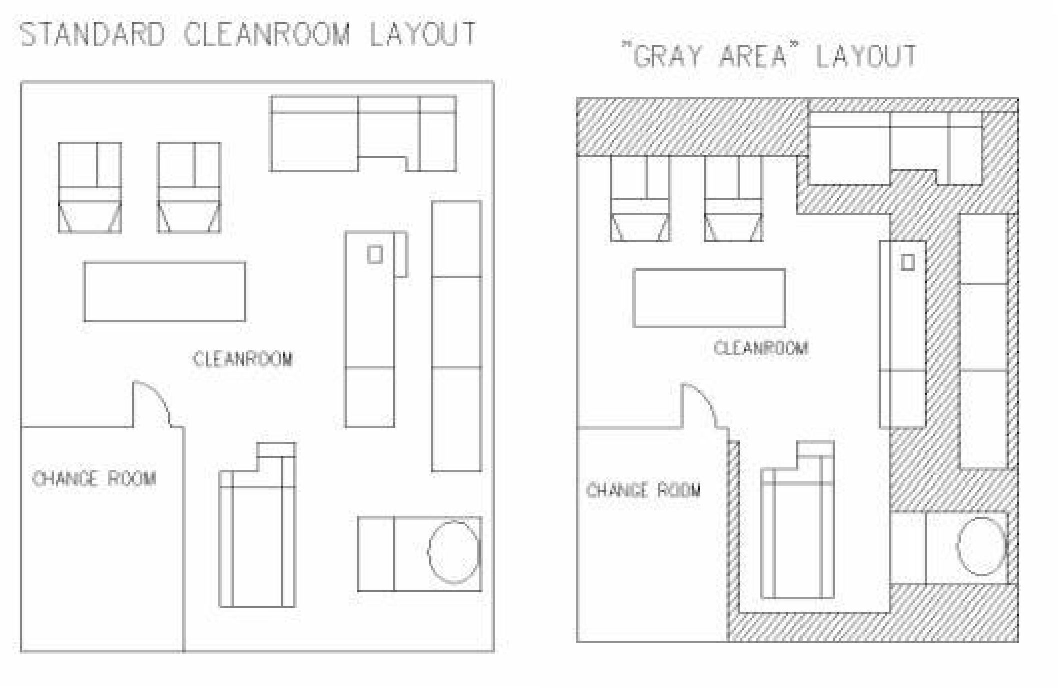
6.9.3. Fume Hoods and Laboratory Modules

Although the choice of whether or not to use the laboratory module concept is based on many factors, it should be noted that relatively small laboratory modules with multiple fume hoods impose more stringent requirements on the ventilation system design. Fume hoods have a major impact on the design and configuration of the laboratory ventilation systems, and their impact will be greatest in rooms where the amount of air flow through the fume hood is large in comparison to the normal ventilation requirements of the room itself. In other words, a fume hood, which can consume as much or more air as is required to ventilate the room itself, will create a need for a precise and highly responsive room ventilation control system. This also translates into the need for accuracy and precision in the design of the ventilation systems themselves. In contrast, larger laboratory rooms (e.g., in a teaching laboratory) will be less impacted by the changing air flow of a single fume hood and will be able to better absorb the effects of changing fume hood airflow. (31)

6.9.4. Clean room Modules

Along with the ever-increasing cost of clean rooms, a design trend has developed to reduce the area of the clean room by placing the process equipment outside the clean room envelope into modular "Gray" areas. The use of Gray areas reduces the volume of the actual clean room proper and modularizes the tasks necessary to operate the clean room. This leads to a downsizing of the environmental conditioning systems and a commensurate lowering of their operating costs. Much of the normal maintenance and chemical distribution can now be done in the Gray area instead of in a clean room area. This helps lower the number of people in the clean room, further reducing the operating costs by controlling contamination. Another side benefit is that adjustment and maintenance activities can now be done in the Gray area more quickly and efficiently. (32)

Figure 6.9.4. **Clean Room Modules**



Source: Briner, 1986

6.10. Utility Service Spaces

There are many utilities, ducts, and electrical services that must be distributed throughout the laboratory facility. Providing orderly pathways and routing for these will reduce energy use and space requirements and make future maintenance easier. (33)

- **Utility Coordination**

To provide efficient horizontal and vertical pathways for the ducts and pipes required for HVAC, plumbing, communications, and electric power requires a great deal of coordination among designers, and engineers. The location of these pathways is normally determined by the facility's function, systems access, and first cost and does not consider the energy waste incurred by inefficient routing of these services.

- **Access Space**

All designs require access space during the original installation and for maintenance and remodelling during the life of the facility. Energy engineers should be involved in the design of access spaces as early as possible. There are many ways of servicing or providing pathways for services in laboratory buildings, but only a few basic approaches ensure an energy-efficient design. The energy engineer should keep in mind that the laboratory planning module and the structural system could be in conflict with energy-efficient utility design, which would impair the efficient routing of utility services during original installation, as well as during future renovations. (34)

- **Suspended Ceiling Layout**

A generous vertical floor-to-floor dimension is essential in laboratory facilities to provide adequate space for the horizontal mechanical and electrical distribution systems. These systems can be placed above a suspended, accessible ceiling. The floor-to-floor height typically includes the functional space, as well as mechanical, electrical, and structural systems. The energy engineer should track space assumptions constantly as the structural and mechanical engineers refine their calculations. Frequently these refinements lead to floor-to-floor height contractions that will "squeeze" the efficient sizing of the HVAC systems. Early designs probably will be based on an assumed ceiling height or on the height of the light fixture above the finished floor. This height varies from 8ft. 0in. to 11ft. 0in. above the finished floor. The low ceiling height of 8ft. 0in. will depend largely on the size of the space and will reduce the volume of air when ventilation rates are based on air change rates. Heights of 11ft. 0in. and higher will depend on the size of the space as well and will affect lighting calculations in the energy use of the space. (35)

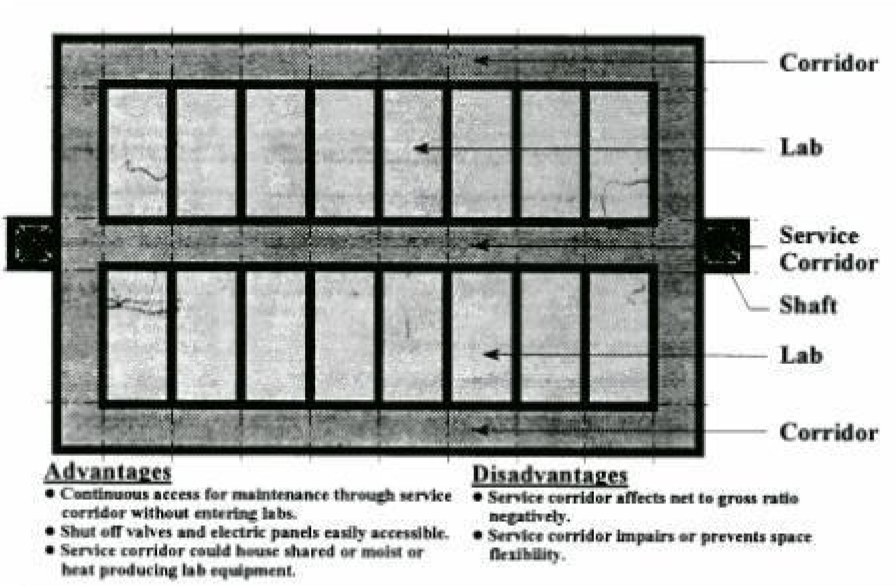
- **Utility Corridor**

In another approach, the engineer can site the distribution system between laboratories instead of above them. Here, the laboratory spaces are adjacent to an accessible utility corridor which houses horizontal duct and pipe runs above head height. The ducts and pipe distribute horizontally into individual laboratories through their ceiling space. Laboratory benches are serviced through the wall from the utility corridor. The design still requires vertical shafts for ducts and pipes to rise or drop to mechanical spaces. The advantages of the utility corridor approach are smooth routing for energy efficiency and easy access for changes and maintenance. The disadvantages are the additional floor area required and a constraint on the ability of the back-to-back laboratories to communicate or expand. (36)

Figure 6.10. (I) **Access Space**

Source : [Ruys, 1990; Cooper, 1994]

Figure 6.10.(II) **Utility Corridor**

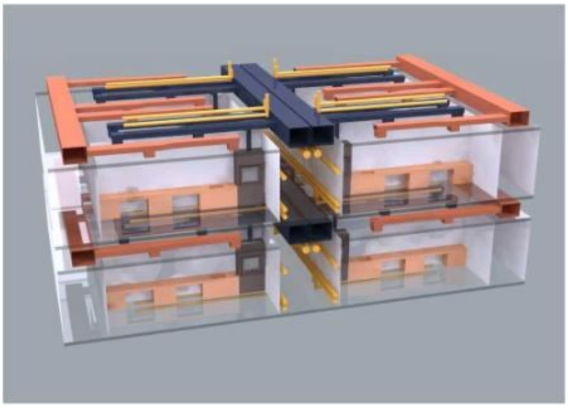


Advantages
- Continuous access for maintenance through service corridor without entering labs.
- Shut off valves and electric panels easily accessible.
- Service corridor could house shared or moist or heat producing lab equipment.

Disadvantages
- Service corridor affects net to gross ratio negatively.
- Service corridor impairs or prevents space flexibility.

Source : [Ruys, 1990; Cooper, 1994]

Figure 6.10.(III) Suspended Ceiling Layout

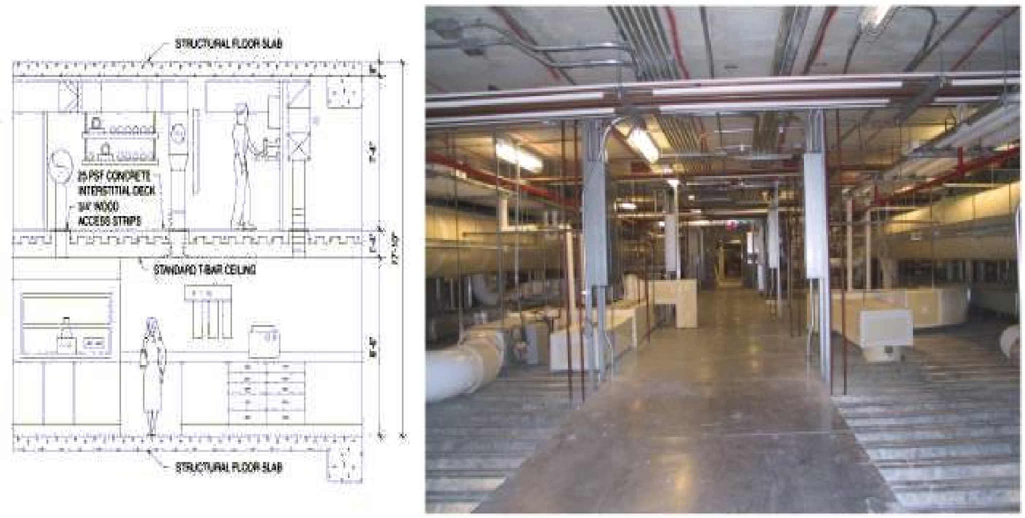


Source : [Ruys, 1990; Cooper, 1994]

- **Interstitial Space**

This arrangement uses an accessible space above the ceiling plane with a floor for access and a low vertical height to accomplish a horizontal distribution of systems. The HVAC and services drop (or rise) vertically from this space into the laboratory envelope and connect to the benches and equipment. Ventilation air is typically distributed from above the laboratory space it serves. An interstitial space or a mechanical loft space has excellent advantages to provide energy-efficient layouts of the services required for laboratory-type facilities. They provide excellent access for maintenance personnel. Vertical shafts at the perimeter or in a central core connect interstitial space services with the entire building. The disadvantage compared to other approaches is the high cost, but use of interstitial space provides good long-term adaptability and a more efficient maintenance program. (37)

Figure 6.10. (IV) Interstitial Space



Source : [Ruys, 1990; Cooper, 1994

6.11. Retrofits

Two of the most successful methods of modernizing an older building are to use the interstitial or "exostitial" mechanical/electrical service space. The interstitial space concept may require appropriating existing usable space. Exostitial space is the addition of service space to the building volume at the perimeter or on top of existing space. Although the cost of providing this service space is high, there may be no other options available when retrofitting certain facilities. There is significant flexibility to this method. Either concept permits the installation of energy-efficient "plug-in" laboratory adaptations which reduce the expense of repeated system modifications. (38)

6.12. Performance Measurement

Laboratory facilities are unique environments that require dynamic operation of various interactive systems, in contrast to standard office buildings. These dynamic, interactive systems can include variable air volume (VAV) supply, fume hoods, and exhaust systems that require positive and negative pressure differentials between laboratories and support spaces. Therefore, commissioning should evaluate and measure the entire facility's performance. The Performance Measurement phase of commissioning assesses the system's actual performance and functioning status and compares the results with the design specification. Baseline performance data are compiled to verify the design performance predictions and to assist in the efficiency assurance commissioning phase. All critical components are tested to determine their performance, suitability, and reliability. "Stress conditions" are created to determine the laboratory systems' control ranges. A fundamental concern is to determine the facility's stability and ability to recover from periods of transition and emergency. (39)

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SECTION B:
SUSTAINABIITY ISSUES

6.14. General Considerations

A typical laboratory facility currently uses five times as much energy and water per square foot as a typical office building. Both academic and research facilities are so energy voraciousness for a variety of reasons:

- They contain large numbers of containment and exhaust devices;
- They house a great deal of heat-generating equipment;
- Users require 24-hour access; and
- Irreplaceable experiments require fail-safe redundant backup systems and uninterrupted power supply (UPS) or emergency power. (1)

In addition, these facilities have intensive ventilation requirements—including "once through" air—and must meet other health and safety codes, which add to energy use. Examining energy and water requirements from a holistic perspective, however, can identify significant opportunities for improving efficiencies while meeting or exceeding health and safety standards. Sustainable design of laboratory environments should also improve comfort and users well being.(2)

Figure 6.15. :**The EPA Campus at Research Triangle Park, North Carolina**

Source: WBDG, 2008

The EPA Campus at Research Triangle Park, North Carolina (see above picture) , which includes laboratory and administrative facilities, showcases flexible laboratory planning concepts incorporated with sustainable features such as daylighting, high-efficiency lighting, green building materials, and comprehensive construction waste recycling to create facilities that balance concerns related to cost, function, and the environment.

6.15. Architectural Considerations

The design of the building envelope—including overhangs, glazing, insulation, and (possibly) the use of photovoltaic panels—plays a large role in the laboratory facility's energy efficiency. (3)

6.15.1. Overhangs

The stepped design at NREL's Solar Energy Research Facility (see bellow figure) provides overhangs and light shelves to shade and direct natural light into the office spaces inside. Overhangs for shading windows are often designed as part of the wall system to improve the quality of the natural light entering the interior space. The south elevation should have a horizontal overhang; east and west elevations usually require both horizontal and vertical overhangs. (4)

Figure 6.15.1: **Sun Control and Shading Devices**

Source: WBDG, 2008

6.15.2. Glazing

The glazing material for exterior windows should have a thermal break and an insulating section between the inner and outer sections of the frames. Wood or fiberglass frames will give much better thermal performance than aluminum. Low-E windows with at least an R-3 insulation value should be used. "Superwindows" that incorporate multiple thin plastic films can have an R value as high as 12. The problem is that such windows cost up to four times as much as low-E glass. Operable windows generally will not reduce energy costs; in fact, they may increase energy usage, but they usually enhance the quality of the indoor environment and are therefore preferred by most clients. See also WBDG Windows and Glazing. (5)

6.15.3.Roofs and Walls

The use of light-colored roofing with a high-albedo coating to reflect light and heat is recommended. The amount of wall and roof insulation needed will vary depending on the climate and the type of lab. For example, equipment-intensive labs will generate a lot of heat and in certain parts of the country will not require as much roof insulation as elsewhere. All electrical outlets and all plumbing and wire penetrations into the building should be sealed, since air leakage can be a significant source of energy waste as well as moisture problems in some parts of the country. (6)

Today, there is quite a bit of discussion about using photovoltaic panels both to enclose a building and to generate electricity. Photovoltaic panels can be integrated into the building envelope as metal roofing, spandrel glazing, or semi-transparent vision glazing. But the panels are difficult to justify in traditional applications because the electricity they generate can cost more than electricity purchased from the grid.

6.16. Engineering Considerations

Sustainable engineering addresses civil engineering concerns as well as the design of mechanical, plumbing, and lighting systems. First and foremost, the design team and client should contact the local utility company to explore opportunities for rebates to assist in the purchase of high-efficiency equipment or the implementation of other energy conservation measures.

6.16.1. Civil Engineering

Civil engineering issues to consider include the use of pervious materials and light colored wherever possible. In preparing a site for new construction, designers should consider transplanting existing trees instead of removing them. Proper storm water management strategies are also important to reduce erosion and replenish local aquifers..

6.16.2. Mechanical, Plumbing, and Water Conservation Strategies

For the HVAC system, it is most important to simulate the operation of the whole system and to analyze assumptions using whole-building systems analysis software such as DOE. Reducing building loads is critical to improving energy efficiency, and one key way to reduce loads is to reduce the amount of outside air used for ventilation. This raises a design challenge, however, since air supplied to laboratories is exposed to chemical contaminants and therefore cannot be returned to the central air handling system and must be exhausted. The volume of ventilation air required for the laboratories is typically greater than that for classrooms, lecture halls, and offices. One strategy to utilize outside air efficiently is to install a mechanical unit that introduces 100 percent outside air into classrooms and lecture halls. Return air from these areas is reconditioned through the mechanical system and then ducted to the laboratories as supply air. The supply air to the laboratories is exhausted. In this way, the outside air is used twice before being exhausted. Note that this strategy may reduce the ability to transform classrooms into lab spaces in the future. (7)

Figure 6.16.2 : **Louis Stoke Laboratories' Building**

Source: WBDG, 2008

The desiccant energy recovery wheel shown here is just one of the energy-efficient features used at the Louis Stoke Laboratories' Building 50. It is estimated that the facility will require 40% less energy than a traditional research laboratory—Bethesda, MD. Electronic air cleaners help minimize air resistance from filters. (8) Maintenance is also important. Effective filter-replacement schedules help keep indoor air quality high and conserve energy. Control systems for variable speed drives on pumps, fans, and compressors should be used only if the controls will be regularly maintained and calibrated. The Fred Hutchinson Cancer Research Center in Seattle, WA was retrofitted to reduce sterilizer water use and water waste, resulting in an annual saving of 10,000 gallons of water. Numerous strategies can be employed for improving the energy efficiency of cooling, heating, and plumbing systems:

- Insulate hot water, steam, and chilled water piping.
- Maintain condenser water as cool as possible, but not less than 20 degrees above chilled water supply temperature.
- Reuse wasted heat with a heat recovery system.
- Install an economizer at the boiler. (The water-side economizer will help with humidity controls.)
- Maintain hot water for washing hands at 105 degrees F. Consider using local hot water tanks at kitchens, restrooms, and other areas instead of central hot water.
- For plumbing systems, consider using ultra-low-flow toilets (0.5 gallons per flush), waterless urinals, dual flush toilets, ultra-low-flow lavatory faucets, and automated controls such as infrared sensors for faucets.
- Harvesting rainwater and reusing "gray water" from sinks for irrigation may help reduce water cost

6.16.3.Sustainable Lighting Design

Sustainable lighting design reduces energy use while enhancing employee comfort and productivity. Sustainable lighting strategies include the use of compact fluorescents (CFLs) rather than incandescent lamps, maximizing natural day lighting throughout a facility, and employing various photo sensing technologies to conserve energy. Incandescent lamps are extremely inefficient, energy-wise, using only 10 percent of the energy they consume to produce light (the rest is given off as heat). CFLs should be used instead. Research office lighting can be less than 0.75 watts/sf. connected load, and with lighting controls it may consume less than 0.5 watts/sf. Where functional requirements permit, lighting design should combine task and ambient lighting to reduce the high overall light levels. Good task lighting lessens glare and eyestrain. (9)

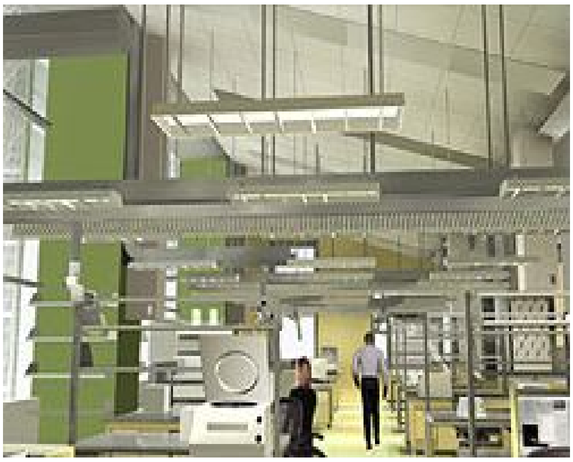
Figure 6.16.3; **Energy Efficient Lighting**.

Source: WBDG, 2008

6.16.3.1. Daylighting

Maximizing the availability of natural daylight is an important principle of sustainable design. Not only does it reduce energy use, but it also increases comfort and enhances productivity. Designers should strive to direct natural light into most laboratory spaces and public areas so that, from almost anywhere in the building, people have the opportunity to look outdoors to see what the weather is like and orient themselves to the time of day. (10) Wherever possible, daylighting should be the primary source of illumination; artificial lighting should be thought of as a supplement to, rather than a replacement for, daylighting. Typically, the first 15 feet of depth at the perimeter of the building can be entirely lit by daylight during the daytime. The use of light shelves can extend the daylight zone as far as 45 feet into the building. Clerestory windows and skylights can be used to get even more natural daylight into the building. See also WBDG Day lighting. Daylighting control systems determine the amount of light available in a given space and switch off one or more banks of lights whenever there is enough sunlight. Both full-range and step fluorescent dimming systems work well. (11)

Figure 6.16.3.1; **Source St. Louis, MO**



Source: WBDG, 2008

6.16.3.2. Lighting Controls

Nidus Center for Scientific Enterprise, a 41,000-sf plant and life sciences business incubator located on Monsanto's Creve Coeur research campus, features daylighting and lighting controls for energy efficiency and occupant comfort. A 30% reduction in energy use was achieved compared to what could have been expected from a conventional lab facility despite a massive turner over that equals 24-hour per day lab use. A key principle to remember in regard to lighting control systems is "simpler is better." Some systems employ photosensing technologies. Photosensing devices can control off-on for exterior lights, triggering fixtures to add light to a particular area when light levels decline. Also, a number of new fluorescent and metal halide fixtures are available that employ daylight harvesting—storing solar energy in the fixture during daylight hours and then using that energy to run the lamp when daylight diminishes; outdoor lighting systems can easily be retrofitted for these fixtures. Other photosensing technologies include programmable low-voltage control systems and occupancy sensors. (12) The programmable low-voltage systems can control individual areas of the building or an entire building with one switch. These systems interface with the building automation and dimming systems. They are flexible, can easily accommodate building changes, have a local override capability, and can be used for large or small systems. Occupancy sensors typically have a one-to-two-year payback. The sensors are designed with adjustable sensitivity levels and timing. There are two technologies: passive infrared and ultrasonic. Passive infrared sensors detect movement of heat between zones. They must have "a line of sight" to detect people in the lab. Ultrasonic occupancy sensors work by broadcasting ultrasonic sound waves, analyzing the returning waves and detecting movement through Doppler shifts. They are effective for larger rooms and can cover a 360-degree area. One problem is that air turbulence can trigger their operation. All occupancy sensor systems must be designed correctly to avoid nuisance operation. (13)

Figure 6.16.3.2. **Electric Lighting Controls**

Source: WBDG, 2008

6.16.4. Other Sustainability Issues

Other sustainable design issues include direct digital control energy management systems, and commissioning the entire building to ensure that building systems are operating as efficiently as possible. Laboratory facilities should be designed with long-term flexibility options, such as the lab module for all architectural and engineering systems, easy connects and disconnects to the engineering systems, and flexible casework. Computers that turn themselves off during non-working hours reduce energy use and cost by reducing cooling loads and electrical demands. Laptop computers use one-tenth the energy of desktop PCs. Clients are pushing project design teams to create research laboratories that are responsive to current and future needs; that encourage interaction among scientists from various disciplines; that help recruit and retain qualified scientists; and that facilitates partnerships and development. As such, an entire and yet separate chapter on Trends in Laboratory Design is been devoted to be most complete of all.(14)

6.16.5. Conclusion

All the architectural, engineering, and other sustainability issues should be studied on a project-by-project basis (see chart bellow). Factors such as the client's specific goals, the type of lab being designed, the part of the country where the lab is located, and its position on the site will lead to different solutions. See also "Whole Buildings" Design Approach. The U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) have launched a new, voluntary program to improve the environmental performance of U.S. laboratories called the Laboratories for the 21st Century (Labs21) initiative. Labs21 is designed to improve laboratory energy and water efficiency, encourage the use of renewable energy sources, and promote environmental stewardship. Also available is the Labs21 Environmental Performance Criteria (EPC), a rating system specifically designed to assess the environmental performance of laboratory facilities. Key aspects of sustainable laboratory facility include:

- Increased energy and water conservation and efficiency
- Reduction or elimination of harmful substances and waste
- Improvements to the interior and exterior environments, leading to increased productivity
- Efficient use of materials and resources
- Recycling and increased use of products with recycled content.

The following table is an example of a sustainable design criteria chart set up for a specific laboratory project. Each criterion must be reviewed for each specific project.

Table 6.16.5: **Sustainable Design Criteria Chart**

Sustainable Design Criteria				
Parameter	**Code Minimum**	**Code Reference**	**Standard Practice**	**Design Target**
Ventilation	10 cfm/person	ASHRAE 62/89	Same	Maximize outdoor air in the breathing zone
Filtration	none		35-80%	65% pre filter 85% final filter
Indoor Design Temperature	75° F summer 72° winter		Same	
Humidity Control	uncontrolled		uncontrolled	60% RH summer 40% RH winter
Equipment Heat Dissipation	NA		3-4W/sf	1.5W/sf or 2W/sf with 75% diversity factor
Toilet Exhaust	50 cfm/fixture	ASHRAE 62/89	Same	2 cfm/sf
Connected Lighting Heat Load	NA		2W/sf	0.5-0.75W/sf Total task/ambient with occupancy sensors and daylight sensors
Lighting Levels	100 ft. candles all direct		Same	20-30 ft. candles with ambient and task lighting
Building Shell Infiltration	6"/100 sf	ASHRAE guideline	3"/100 sf	1.5"/100 sf (Canadian Standard)
Building Shell Infiltration (alternate)	0.60 cfm/sf	ASHRAE guideline	0.30 cfm/sf	0.10 cfm/sf
Exterior Wall Insulation	U = 0.28 btu/sf-hr- F	BOCA Energy Code	0.10 btu/sf-hr-F	U = 0.15 btu/sf-hr South U = 0.05 btu/sf-hr (N, E, W)
Exterior Wall Moisture Control	none			AIB - with insulation both sides
Roof Insulation	U - 0.07 btu/sf-hr	BOCA Energy Code	U - 0.05 btu/sf-hr- F	U - 0.05 btu/sf-hr- F with low albedo surfacing
Windows				
Glazing type	Single/clear		Double/clear	heat reflecting clear
Visible transmittance	0.80		0.78	0.70
Shading Coefficient	1.00		0.80	0.43
U value	1.04		0.48	0.30
Heat Degree Days	6,155 btu	ASHRAE	Same	Determined by DOE-2 or other energy analysis of TMY data

Source Laboratories for the 21st Century, 2008

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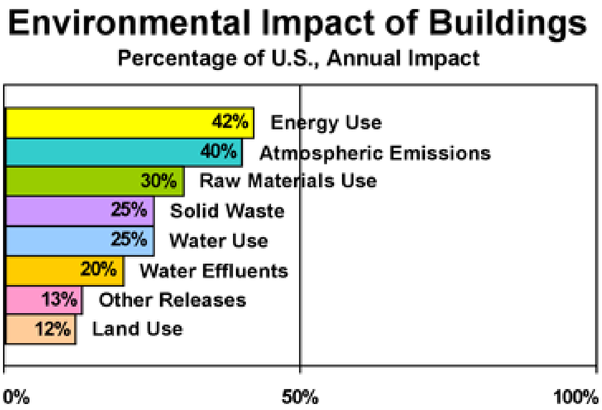
SECTION C
ENVELOPPE SUSTAINABILITY

6.18. General Sustainability Impacts

Since the early 1990s, sustainability has become an increasing priority for facilities projects. It is no secret that building construction and operation have an enormous direct and indirect impact on the environment in terms of energy use, atmospheric emissions, use of raw materials, waste generation, water use, and many other factors. As economy and population continue to expand, the design, construction and operation community will face increasing challenges to meet the new demands for facilities that are accessible, secure, healthy, and productive while minimizing their impact on the environment. (1)

Figure 6.18



Source: Levin, H. (1997)

For the design, construction and operation of a facility, there is an especially important interface between the indoor and outdoor environments, that of the building envelope. The building envelope is comprised of the outer elements of building—foundations, walls, roof, windows, doors and floors. (2) The prime functions of the building envelope are to provide shelter, security, solar and thermal control, moisture control, indoor air quality control, access to daylight, and views to outside, fire resistance, acoustics, cost effectiveness and aesthetics. Because of the varied and sometimes competing functions associated with the building envelope, an integrated, synergistic approach considering all phases of the facility life cycle is warranted. (3) This "sustainable" approach supports an increased commitment to environmental stewardship and conservation, and results in an optimal balance of cost, environmental, societal, and human benefits while meeting the mission and function of the intended facility.(4)

6.19. Description

The main objectives of sustainable design are to avoid resource depletion of energy, water, and raw materials; prevent environmental degradation caused by facilities and their infrastructure throughout their life cycle; and create built environments that are accessible, secure, healthy, and productive. While the definition of what constitutes sustainable building design, construction and operation is constantly evolving, there are six fundamental principles that nearly everyone agrees on. (5)

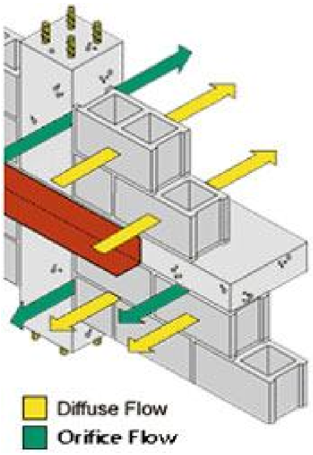
6.19.1 Optimize Site Potential

Creating sustainable buildings starts with proper site selection, and the location, orientation, and landscaping of a building affect the local ecosystems, transportation methods and energy use. (6)

6.19.2. Minimize Energy Consumption

A sustainable building should rely on efficiency and passive design measures rather than fossil fuels for its operation. It should meet or exceed applicable energy performance standards (see figure belw). (7)

Figure 6.19.2 **Air Leakage through a Building Enclosure**



Source: WBDG, 2008

6.19.3. Protect and Conserve Water

In many parts of the country, fresh water is becoming an increasingly scarce resource. A sustainable building seeks to reduce, control, and/or treat site runoff, use water efficiently, and reuse or recycle water for on-site use when feasible.(8)

6.19.4. Use Environmentally Preferred Products

A sustainable building should be constructed of materials that minimized life-cycle environmental impacts such as global warming, resource depletion, and human toxicity. In a material context, life cycle raw materials acquisition, product manufacturing, packaging, transportation, installation, use, and reuse/recycling/disposal.

- Enhance Indoor Environmental Quality (IEQ)—the indoor environmental quality of a building has a significant impact on occupant health, comfort, and productivity. Among other attributes a sustainable building should maximize day lighting, provide appropriate ventilation and moisture control, and avoid the use of materials that are high in VOC emissions.(8)
- Optimize Operational and Maintenance Practices—incorporating operating and maintenance considerations in to the design of a facility will greatly contribute to improved work environments, higher productivity, and reduced energy and resource costs. Designers are encouraged to specify materials and systems that simplify and reduce maintenance requirements; require less water, energy, and toxic chemicals and cleaners to maintain; and are cost-effective and reduce life-cycle costs.(9)

6.20. Emerging Issues

6.20.1. Balancing Security/Safety and Sustainability Objectives

Providing for sustainable designs that meet all facility requirements is often a challenge to the building design, construction and operation community. With limited resources it is not always feasible to provide for the most secure facility, the most architecturally expressive design, or energy efficient building envelope.(10) From the concept stage through the development of construction documents, it is important that all project or design stakeholders work cooperatively to ensure a balanced design. Successful designs must consider all competing design objectives. (11)

6.20.2. Integrated Design

Designers are moving away from the conventional building design approach that has historically resulted in little interaction between all parties involved in the project. There is a movement to embrace integrated building design, fostering communication amongst all parties that could be involved in the project, and facilitating *working together from the start* to coordinate and optimize the design of the site and the building. (12)

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CHAPTER SEVEN

POST OCCUPANCY EVALUATION A PERFORMANCE BASED APPROACH: CONCEPTS AND TOOLS

7.1. Introduction

Post Occupancy Evaluation (POE) is considered an important stage of the implementation loop for projects, allowing for feedback of evaluation results and consequent lessons into the planning stages of future projects. Although the use of POE is on the increase, the lessons learnt are not always adequately communicated or used for the purposes intended. In the forgoing chapter we shall review the specialised literature in order to unveil some aspects relating to POE as a Performance Based Approach (BP). At thorough literature search undertaken for this purpose tends to pin out that at present, the debate about a one all encompassing definition on POE performance based approach is far from having found the consensus in both terms concept and applicability alike. Nonetheless, literature evidence stressed with a shadow of a doubt that information from POEs can provide not only insights into problem resolution but also provide **useful benchmark data** with which other projects can be compared. This shared learning resource provides the opportunity for improving the effectiveness of building procurement where each institution has access to knowledge gained from many more building projects than it would ever complete.

In doing so, methods in current use and their relevance to the design of laboratory building will be highlighted. Another concern along these lines will lie on the identification of major POE methods liable to enhance quality of the built environment. Various definitions of Post-Occupancy Evaluation (POE) have been advanced over the last 20 years since the term was coined. Loosely defined, it has come to mean any and all activities that originate out of an interest in learning how a building performs once it is built, including if and how well it has met expectations and how satisfied building users are with the environment that has been created. POEs can be initiated as research, as case studies of specific situations, and to meet an institutional need for useful feedback on building and building-related activities.

International experience in the field of POE is opportunely taken into account for the sake of making better living and built environments. Furthermore, concepts and tools in current use are specifically discussed; this to underscore the venues capable to set forth a POE performance based approach framework in relation to meet evaluation objectives in relation to the forgoing topic of the design of laboratory design.

7.2. Background & Literature Search

The literature reviewed includes sources from the USA, Canada, UK, New Zealand and Australia. Almost all sources quoted studied POE in terms of a range of largely similar issues that included the main purpose of POE, the reasons why more are not carried out; the main types undertaken plus suggestions were often supplied for useful techniques for actually undertaking them. Most analysts would appear to be in general agreement that Post Occupancy Evaluation (POE) should be an integral component of the building procurement process.(1) There is logic to the argument that one purpose for the evaluation of buildings in-use must be the provision of essential feedback to inform future actions. However despite the often 'clear-cut' case in support of POE, many commentators are also in agreement that POE has, by-and-large, been neglected by industry in general and the design professions in particular. (2) In the UK, POE has suffered almost 40 years of continued neglect. In particular, the use of POE as a feedback loop to the design process has proved to particularly intractable. As Vischer comments "... in spite of the logical imperative to link POE results to the front end of the design process, efforts to do so have had to struggle to survive." (3) In the last decade, there has however been renewed interest in POE fuelled by the emergence of facilities management as a major discipline in the procurement and management of buildings. (4). The research described in this paper is indicative of this resurgence of interest in POE.

7.3. Post-Occupancy Evaluation A Chronological Glance

Post-occupancy evaluation of educational buildings and has nearly a forty-year history. The Building Performance Research Unit (BPRU) at the University of Strathclyde appraised over fifty comprehensive schools in Scotland during the 1960s. The bulk of data generated since then provided seminal determinants of post-occupancy evaluation applied to school buildings. Techniques that relate space and its organization to people's responses, space use, costs, services and movement were developed. First by the BPRU team from the 1972 onwards. (5)

In the United States, Rabinowitz (1975) (6) reported on a diagnostic post-occupancy evaluation conducted in four schools in Columbus, Indiana that looked comprehensively at technical, functional and behavioural aspects of each school. Data collection through observation, photography and surveys was compared to existing standards. (7)

In an effort to standardize the evaluation of educational facilities, a guide was first developed by the Council of Educational Facility Planners International (CEFPI) in 1986 that provides evaluative criteria for administrators and community leaders to measure the quality of facility for general condition and suitability for education. Over 125 items affecting the functioning of educational buildings are offered in six areas: sitting, structural and mechanical features, plant maintainability, school building safety and security, educational adequacy and environment for learning. The stated purpose of the appraisal includes the performance of a post-occupancy evaluation, to formulate a permanent record to document deterioration, to highlight specific appraisal needs, examine the need for new facilities or to evaluate the need for renovation, as well as to serve as an instructional tool. Since that, the concept has gained universal approbation and is nowadays frequently used. There are also many other abbreviations meaning same process: Building Evaluation (BE), Facility Performance Evaluation (FPE), and different types of customer satisfaction surveys. In connection with customer surveys certain aspects have to be taken into daylight. (8)

7.4. What is Post Occupancy Evaluation?

Post Occupancy Evaluation (POE) is acknowledged and longed-for as a process that can enhance, and help to describe, the performance of the built environment. (9) Briefly, it’s a process of evaluating buildings in a systematic and accurate way after they have been occupied for some time).(10) It is also characterised by all-inclusive and yet thorough assessment of a building. However, POE methods spin around the study of the efficiency lying in the users / environments interface. (11)(12)

The result of the method will revolves about two broad features that relate mainly to the strengths and the weaknesses of a building. The results are usually replicated, because the method tough systematic can be adapted to other cases. In addition to repeatability, the results are very valuable chiefly in the building development. Development aspect is perceived by many stakeholders; including architect, engineers, tenants, owners and consultants. Mostly POE is targeted to occupants’ point of view. This utilisation is only limited by the structure how POE is conducted. (13)

POEs are more than “customer surveys”; they are absorbed in the profound building essence. It is obvious but this systematic investigation and analysis of the structure and relationships between design objectives and occupants’ experiences is taken into consideration in future development efforts. (14)

Another way of looking is the verification purposes. We need to be sure that the intensions of the design have really become true. We need to determine whether the finished building actually meets the specified attributes. Therefore, post occupancy evaluation methods are needed. (15) As mentioned earlier, POEs are useful to everyone who comes into contact with a building. POE is a powerful diagnostic tool that allows people to learn about their past, mistakes and successes alike. (16)

The purpose of tool is simple: it helps practitioners to avoid repetitive mistakes. First, it needs to have two sided opinions, both researchers and the target audience. Second, it improves buildings and procedures many ways like:

-reduction of the design and maintenance costs

-increase of the customer satisfaction

-more comfort

-better performance

-increase of the attraction in the building

-solve problematical issues

-investment payback time modification.

Evaluation and feedback are the cornerstones for the continuous improvement in building procurement sought by the Higher Education sector. Good feedback is an intrinsic part of good briefing and design of buildings. A recent report produced by CABE shows that well-designed buildings are a significant factor in the recruitment of staff and students in Higher Education. To be most effective building performance evaluation must happen throughout the lifecycle of the building. (17)

In this thesis the term POE is used as an umbrella term that includes a review of the process of delivering the project as well as a review of the technical and functional performance of the building during occupation. POE is a way of providing feedback throughout a building's lifecycle from initial concept through to occupation. The information from feedback can be used for informing future projects, whether it is on the process of delivery or technical performance of the building. It serves several purposes: (18)

Short term benefits of POE

- Identification of and finding solutions to problems in buildings;
- Response to user needs;
- Improve space utilisation based on feedback from use;

Medium term benefits of POE

- Built-in capacity for building adaptation to organisational change and growth;

- Finding new uses for buildings;
- Accountability for building performance by designers

Longer term benefits of POE

- Long-term improvements in building performance;
- Improvement in design quality;
- Strategic review

The greatest benefits from POEs come when the information is made available to as wide an audience as possible, beyond the institution whose building is evaluated, to the whole Further Education sector and construction industry. Information from POEs can provide not only insights into problem resolution but also provide useful benchmark data with which other projects can be compared. This shared learning resource provides the opportunity for improving the effectiveness of building procurement where each institution has access to knowledge gained from many more building projects than it would ever complete. It is a key concern that information is structured so that institutions can compare against benchmark and other codes and standards. (19)

7.5. Definitions

There are a number of definitions of POE, all generally in accord with, and built round the central theme of the simple statement.(20) that “post-occupancy evaluation (POE) is the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time” .(21) loosely defines POE as meaning “any and all activities that originate out of an interest in learning how a building performs once it is built, including if and how well it has met expectations”. The RIBA Research Steering Group (RIBA, 1991, p.191) defined POE as “a systematic study of building in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have”. (22)

Preiser stressed another perspective i.e. that of the facility manager, defined POE as “a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically”. (23) Clearly a POE may be carried out by a range of different building industry professionals, or as quite often occurs by the client or building owner. However, for the purpose of this study POE was defined as ‘the systematic evaluation of buildings or facilities’ assumed to occur some time after their occupation and usually after a defined period of use such as 12 months to 2 years’.

7.6. Theory

Following Preiser, we can also define FPEs by their activity and resource requirements: Brief. Approach for POE is adjustable, typically evaluations are case related including content and depth is allocated to attain required level. Preiser defined the following basic forms of POE: (24)

Indicative POE

Indicative **POE** aimed at showing the major strength and weaknesses of a particular building; Indicative POEs are carried out by quick walk through evaluations. This involves structured interviews with key personnel, group meetings with end-users, as well as inspections which document building performance photographically or in written form.

- **Investigative POE**

More detailed investigative **POE** aimed at showing the causes and effects of environmental issues of building/s more in-depth and utilizes interviews and survey questionnaires, in addition to photography, video recordings and physical measurements.

- **Diagnostic POE**

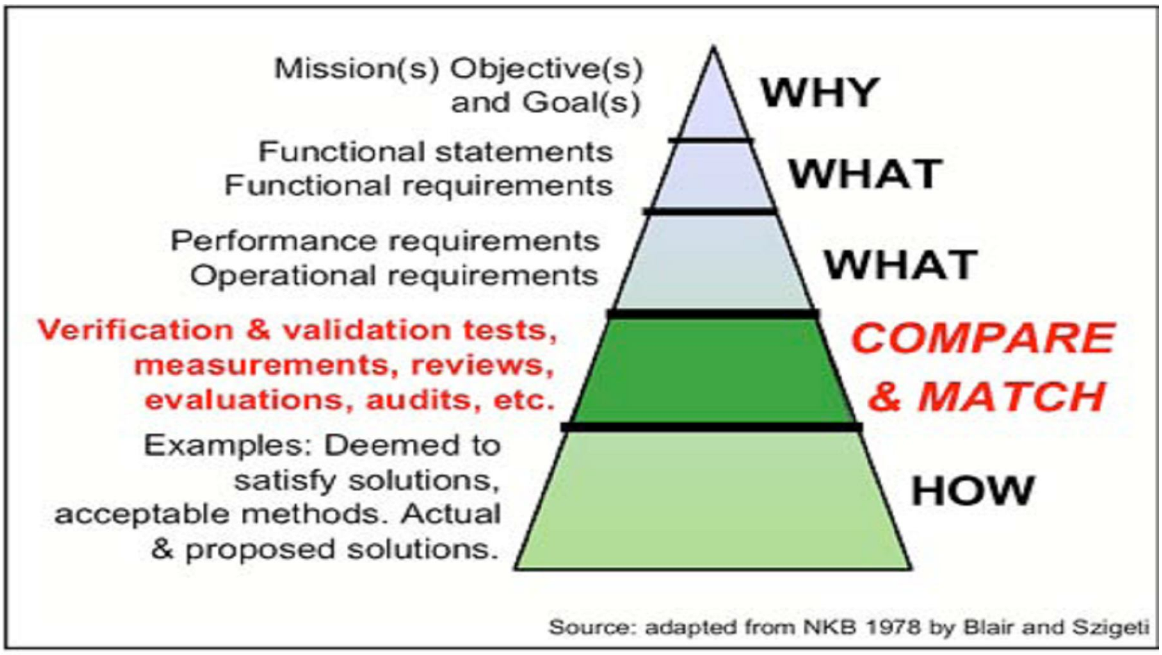
Diagnostic **POE** aimed at correlating environmental measures with subjective user responses**.** Diagnostic POEs are focused, long-term and cross-sectional evaluation studies of such performance aspects as stair safety, orientation and way finding, lighting solution, privacy, overbooking, etc.

7.7. The Nordic Model as a Point of Departure

The search for a different set of methods and tools to complement the traditional prescriptive ones has been taking place in many countries, in the public and private sectors, as well in the regulatory realm. (25)

In the 1970s, the so-called “Nordic Model” (NKB1978) was born. The development of performance-based and objective-base codes is based on key characteristics of the Performance approach, the model and links easily to one of the dialog between the WHY + WHAT and the HOW. (see figure below) .(26) Conceptually the Performance concept requires two languages. On the one hand, there is a requirement (demand) and, on the other hand, there is a capability to meet that demand and perform as required (supply). The language of the client is needed on the demand side and the language of the provider is needed on the supply side.

Figure 7.7. **The Nordic Model**



Source: **Nordic Committee on Building Regulations, 1978.**

These are different and it is important to recognize this fundamental difference. (27) Altogether, an evaluative stance is therefore useful throughout the Life Cycle of constructed assets. In the building and construction industry, prescriptive codes, regulations, standards, and specifications have been perceived as "getting in the way" of innovation, making change difficult and costly to implement, and creating technical restrictions to trade.

These concerns have been the major drivers towards the use of a Performance Based approach to codes, regulations and standards. (28) The overall goal for establishing a performance based approach is the creation of a framework for acceptance of alternative materials, design, and methods of construction, i.e. to facilitate innovation.

7.8. Process

According to Bechtel POEs are usable in different building types and buildings from various eras. It is applicable to new buildings or renovations. (29) wherein POEs are convertible in scale, resources, goals, methods, evaluator expertises, evaluator interests. Furthermore, most of the evaluations have five principle phases in common which are:

a. Entry and initial data collection
b.. Designing the research goals including choosing designs and methods.
3. Collecting data
4. Analyzing data
5. Presenting information.

All POE methods can contain simple or complex case building. Time period is also convertible, depending of the evaluators, extent and type of information what is under investigation. Methods that have been used in completing POE include interviews of building users, questionnaires, observation of environmental activity, checklists, and methods of recording the physical settings, such as energy consumption. Whether there is a variety of different methods in conducting POE, the fundamental purpose is assessing the building successes/strengths and failures/weaknesses from the standpoint of the occupants. (30)

More detailed strategic process has also been presented by Baird. which has been adapted from Preisers' material. Basics are described with more detailed manners and fundamentals of five steps are divided to more extensive phases. Detailed strategic process is described in pages following. (31)

7.9. Planning the POE

7.9.1. Reconnaissance and Feasibility

To initiate the POE project.
To establish realistic parameters regarding the client organisation's expectations of the evaluation.
To determine the scope and cost of project activities.
To obtain a contractual agreement against outsourcing.

7.9.2. Resource Planning

To organise enforcing resources.
To develop all level cooperation and support in the organisation.

7.9.3. Research Planning

To develop a research plan which ensures that appropriate and credible POE results are obtained.
To establish performance criteria for the building.

To identify appropriate data collection and analysis methods.

To develop appropriate instruments.

To allocate responsibility for specific research assignments

To devise quality control procedures

7.9.4. POE STEPS

1. Preliminary inspection of building to be evaluated
2. Determination of existing building documentation
3. Identification of significant building changes and repairs
4. Definition of project parameters
5. Development of work plan, schedule and budget
6. Formation of POE project team
7. Identification of archival resources on client organization documents
8. Inspection of building
9. Development of research instruments
10. Classification and development of performance criteria for the evaluation

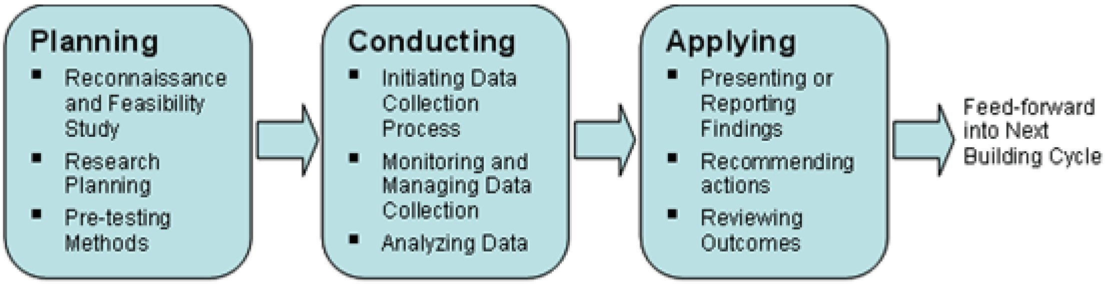
7.10. Phases of FPEs

Typically, there are three phases of FPEs the planning phase consists of reconnaissance and feasibility studies, and research and resource planning. In this phase, the parameters of the project are established; the schedule, costs, and work force needs are determined; and plans for data collection procedures, times, and amounts are laid out.

The conducting phase consists of initiating the on-site data collection processes, monitoring and managing the data collection procedures, and analyzing the data. One important aspect of the conducting phase is to ensure that data being collected meets FPE goals and does not bias the results.

The applying phase consists of preparing documents reporting the findings of analysis, recommending actions, and monitoring and reviewing the outcomes of any such action undertaken. Outcomes are important, because they may be used as a feedback to modify and/or improve the next cycle of FPE processes.

Table 7.10. **Phases of FPEs**



Source: Decision for Support Tools For Performance Based Building, 2004.

7.10.1.Techniques of Data Collection in FPEs

FPEs typically assess the performance of several aspects of buildings and building systems. Techniques commonly used to collect data of building-user relationships, i.e., the FPE/POE techniques, are questionnaires, interviews, field observations, walk-throughs, workshop sessions, photographic surveys, recordings of the use of time, and looking at the physical evidence of use. One key aspect that characterizes FPEs, as opposed to POEs, is that FPEs often involve a much wider range of measures such as technical, economic, and organizational performance. (33) The Workplace 20.20 program uses the balanced scorecard (BSC) to organize a range of building-related outcomes.(32)

Figure 7.10.1: **Data Collection Techniques**

Methods commonly used in FPEs

Interviews, open ended
Interviews, structured
Cognitive maps
Behavioural maps
Diaries
Direct Observation
Participant observation
Time-lapse photography
Video recording
Questionnaires
Psychological tests
Adjective checklists
Archival data
Demographic data

Source: Decision for Support Tools For Performance Based Building, 2004.

At present, Internet and other computer-based technologies are used extensively for conducting FPEs and for analyzing the data generated. Web-based surveys are convenient, have low cost of distribution and return, and also make it easy to receive data and check for errors, and give feedback to respondents.

7.11. POE Tools

7.11.1. Practical Techniques for Undertaking POE:

Basic principles for conducting POE begin with the recommendation that the steps include: a simple, reliable and standardized way should be developed of collecting useful feedback from occupants...on a few, carefully selected and identified indicators of environmental quality". She discusses her conclusions regarding the best practices observed in her case studies and the particular advantages of linking POE with pre-design programming for public agencies or other organisations that repeatedly construct the same building type. She notes however that even in this situation it is not easy to implement, and recommends that an approach be designed ahead of time, process be developed and tested beforehand, and that adequate resources need to continue to be available for the process to be used most effectively. (33)

In summary, these include recommendations regarding standardisation of data collection and reporting, advance determination of to whom POE results will be disseminated, the need for objective collection of data as well as by questioning of users and the appropriate management of user expectations. In Baird (1996) the contributors offer detailed examples of various POE techniques from a range of perspectives that may apply to different project types and evaluation purposes. All the techniques described are carefully structured and generally hierarchical in their application to the process of gathering and analysing POE data from building clients and users. (34)

7.11.2 Data Collection and Analysis

Once the purpose of an evaluation has been determined, relevant project information should be gathered - this will include the size, cost, procurement method, available documentation, program and other project history. The next step is the collection of detailed feedback from those who use the building or facility on a daily or regular basis. Both quantitative and qualitative information are collected and the responses received recorded in a consistent format (templates are provided for this purpose),

Having generally been assessed in terms of agreed assessment criteria or scores. POE may collect data in three main categories - service outcomes (or business performance), facility functionality (fitness for purpose, physical quality, compliance with technical standards) and procurement processes (time, cost, probity compliance, etc). The data may then be collected for one or more categories at three defined levels of complexity i.e. project profile (minimum data set for all capital projects), facilities level data (standard requirements for all projects including general requirements, overall facility performance, etc.) and specific data (for a particular part of a facility such as an operating unit or for a specific small scale element that occurs across many, if not all health facilities e.g. bathroom design or finishes).(35)

7.12. Summary

The process of POE is particularly useful for helping to develop appropriate design standards for laboratory facility that accommodates highly technical processes with many repetitive elements. Many higher education facilities are built each year, often many of the same type are built, on every project achieving best value for the funds expended is always expected and refinement of the process over time is both possible, and probably inevitable. Although higher education laboratory facility are particularly appropriate for application of POE, other institutional type buildings e.g. heath care, schools, prisons, train stations, etc are also highly suitable for this approach. As stated at the onset, the need to conduct POEs as a means of providing essential feedback to inform future actions would appear to be self-evident. The reasons why POEs still remain the exception rather than the rule have been reviewed and some of these have been considered. Not all the reasons for under-use of POE have been addressed in this current study rather it is suggested that the remaining issues fall outside the scope of this research, perhaps requiring future investigation.

This chapter has endeavoured to describe how a research project can assist central government and local authorities in the higher education sector to respond to the challenge of developing a POE methodology which has the capacity to provide consistent ‘evidence based’ information to be incorporated into design guidelines, and inform future higher education facility design decisions. Arguably tough, the potential as well as the limitations of the methodology will require further exploration in use.

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CHAPTER EIGHT:
CASE STUDY.

8.1. Introduction.

This chapter seeks to examine design criteria lying behind the design of higher education laboratory facility in order to draw up enhanced recommendations for future buildings. To achieve this, first, the size and type appropriate to Algerian university buildings is identified. Second a potential sample for further detailed analysis is selected.

The recent trends in the provision of university buildings in Algeria indicate a strong emphasis upon science and technology. The Algerian government aims at providing the entire country with laboratory facility I) to establish up theoretical framework in terms of functional requirements, II) to evaluate the state of fit in relation to user/activity interface and to III) to infill potential recommendations within future guidance so as to enhance the quality of the building stock in years to come. The first encompasses as indicated (sect. 2.2.3.2. [I]), the small universities with student population of 2000 or thereabouts and, second, large or major ones tailored with a student capacity of 10.000 students and above. The average main divisions were science & technology.

Many visits on the Constantine campus site has led that in view of size, academic pattern and activities in current appliance, there seems to be that the campus of Mentouri based at Constantine appears most suitable in many respects:

- The comprehensive records of laboratory facilities.
- Old enough to offer suitable data base with regard to potential changes in both user/activity interface. User satisfaction and building performance.
- There seems to be that initial design schemes obeyed to an extent to most detailed guidance, “driven by the Brazilian architectural firm” whose been in charge in the planning and design of the university of Mantouri.
- Availability of resources to conduct the present field work.

Examination of the relevant literature, pointed that Constantine campus remained the most comprehensive case that could arguably be worth studied so as to induce generic design and technical data that could be applied nationwide with regard to of laboratory facility.

However, given the confines of this study and the time constraint, the detailed study was narrowed down solely to Constantine campus. The field work includes all types’ university laboratory facilities mainly in all three basic scientific disciplines (chemistry, biology and physics). Thus Constantine campus was felt a most comprehensive case that could generate valuable feedback for future.

8.2. The Methodology.

The survey of literature in the previous chapters (Chp.2, Chp.3 and Chp.4) highlighted the complexity in his design of university laboratory facility. It was noted that laboratory facility present peculiar place within it. A key reason in the conflict implicit in laboratory design, which calls for designing for change and growth and yet providing a qualitative and sustainable environment (health, safety and convenience requirements) for immediate use. In order to investigate the extent to which architects have dealt with the above conflict, three broad aims were defined for the proposed case study. These were:

i) To examine whether the array of standards and norms found in the relevant literature and official guides complies with those in current use.

ii) To assess user satisfaction and attitudes with regard to both functional requirements and environmental sustainability provided within the laboratories and their location in the campus.

iii) To examine the extent to which the initial design has allowed for flexibility and adaptability.

According to the Social Services Buildings Research Team (S.S.B.R.T) Report on the 'Appraisal of Buildings', methods and approaches of evaluating the performance of a building vary in relation to the type of appraisal to be undertaken, such as: descriptive, environmental, technical, model or psychological. In congruence with the lines suggested by the S.S.B.R.T the model approach seemed most likely to achieve the three aims ser out above. This evaluation strategy combined several techniques of data gathering, which are: observations, interviews, questionnaires and physical measurements.(3) These were also mentioned in various studies involving evaluation of buildings such as those by D. Canter (1966), D Manning (1968) and R. K. Yin (1984).(4)(5)(6) However, before discussing the techniques outlined above it is first necessary to lay down the criteria which made possible the choice of laboratory sample to be studied.

8.2.1. Choice of Sample.

As shown throughout the prevailing discourse of the present thesis the criteria of size and academic pattern were decisive in selecting the type of laboratory facility within which the case study took place. As the study's main focus is on laboratory facilities, contacts were made with different university users' in order to arrange formal visits to a number of laboratory facilities. Consequently 30 laboratories were selected from the chemistry and the physics schools respectively. Their choice was completely random as none of the laboratory sizes found in use conforms to the standard size of Algerian university laboratory facilities of 30 students. While chemistry Laboratories were organic chemistry (average 40 students) and inorganic chemistry (48 average students), physics Laboratories were general physics (38 students) and electronics (38 students). The prime reason for dismissing biology laboratories was simply the difficulty of getting in touch with the Head of the Biology School during the course of the preparation of the study. Many contacts were unfruitful tough we showed a strong willingness and many appointments were aborted for unreleased reasons. It was felt prudent not to take any step further without due permission. Particular attention should be drawn to the interest showed by various members of staff of both schools visited.

8.2.2. Observation.

For the first source of collecting data, direct observation in a given environment can be carried out using various techniques. The choice of a particular technique is argued to be connected to the type of information sought. According to Zeisel there are five devices suited to recording behaviour observation including notations (verbal description and diagrams), preceded checklists, maps and floor plans, photographs and video or films.(7) Further, Yin reckons that whether it is a casual or a formal observation, in order to increase the reliability of observational evidence, the procedure must be conducted with more than one observer.(8)

In the present case study, observations were made of both components of the laboratory facility built environment (space and activity), to gain access to the events and groups involved and ultimately to record both the physical features of the laboratories and users' attitudes. These were achieved by means of a combination of different tools. Checklists for every laboratory were used to provide a better understanding of some of the physical requirements of the visited laboratories. Additionally, floor plans and maps of the corresponding premises were found useful in locating several physical items (furniture, equipment, fenestrations, etc.). Finally, in order to palliate possible shortcomings of the above two devices (i.e.: checklists and floor plans), photographs were taken 'to capture subtleties that naked-eye based methods may not record'. (9)

8.2.3. Interviews.

Yin argued that 'one of the most important sources of case study information is the interview'.(10) There are different forms of interviews in use, of which the most common are the open-ended and the focused interviews respectively. For this particular case, focused interview, also called semi-structured, were chosen rather than the former type since the chief aim was to corroborate or dismiss certain points already made in previous chapters. (Chp.3 and Chp.4)

8.2.3.1. Interviews With Heads of Schools.

Focused interviewed with Heads of the biology, chemistry and physics schools respectively were carried out. The overriding aims were first to identify the range of scientific activities that take place within each school's laboratories and second, to establish the level of use of laboratory space. Finally, to show any request for change made by either school or the extent of its fulfilment.

8.2.3.2. Interviews With the Users.

The same procedure was followed with members of staff including tutors, technicians and the estates officer as well as with students. These helped to examine staff, students and other related agents(officers of all kinds) attitudes towards the working conditions in terms of health, safety and convenience standards. The other intention was to find out the nature of change that could possibly have taken place since the laboratories were built and subsequently what are (were) the laboratory's compartments most prone to change and how often do (did) these changes (if any) occur.

8.2.3.4. Measurements of Plans.

Measuring plans is another form of compiling data. It involves the measurement of various physical attributes of laboratory space, so that they can be compared against the recommended ones. The main aim was to investigate whether there were any variations or affinities with the standards and norms found in the relevant literature and other official guides.

8.3. Background to Constantine Mantouri Campus.

Figure 8.3: **View of the SCIENCE BLOC lit from above**

Source: WWW.UMC.dz 2008, (visited September 2008)

Figure 8.4: **Views of the Constantine university campus**

La tour principale

Un des amphithéâtres

The project of building the university aroused a great deal of interest since, as, it was intended to lift up central government political aims .(12) The university is situated about a 5 miles or thereabouts from the city centre. It occupies a 35 hectares site on the southern hill slopes Constantine. It was proposed to accommodate 4500 students by 1969 and possibly about 20000 by 1980. However, the total student population in the beginning of the academic year of 2007/2008 amounted to ***62295***, dramatically above all the target set. (13) The academic structure centres on the provision of most places in the subjects of pure and applied sciences. At the present date the university encompasses ***8 faculties***. Each faculty takes general responsibility for its teaching and research activities; all are completely self-contained, so students receive instruction from the faculty board exceptionally from other than their own. (14) As far as the architectural pattern is concerned, the overall layout is based upon a pure a unique concept related to modern architecture in its pure style. Reasons for advocating this pattern stem from the need to provide political impact and growth, as indicated in the statements of the brief. A further cause that could have been at work in the choice of this design paradigm, was that it dispenses ‘general control over relationships and sitting of different types of buildings, and preserves a simple and consistent pattern of communication as university grows in size and complexity’.(15)

The key concept is the esplanade (see figure, around which all university facilities are spread out in a fine interdependency. Yet, architectural critiques argued that this project was a great symbol of central government to show willingness to up lift higher education in the country so as to enhance socio-economic developpement. The concept inspired by architect Oscar Niemeyer tends to be “figé” over time. A comprehensive plan there was little space for extension or future additions. An ended gigantic pair of concrete slabs houses both main classrooms & theatres and on the other the whole bulk of laboratory facilities.

8.4. Description of the Sample.

The design of university laboratory facility with their complex requirements for various kind of space, including larger teaching laboratory areas, research areas, administrative areas, lecture rooms and libraries, has become more problematic and a comprehensive design frame work strategy becomes necessary. Within this context, the search for such strategy in the case of Constantine Mentouri University culminated in the adoption of a peculiar pattern.

The Schools of Chemistry, Biology and Physics, occupy the West Concrete slab. A great deal of similarity exists between faculties. All laboratories are set on each side of a 200 metres long corridor spine 6 m wide. Allocation of space sprang initially from the nature of activities. Thus, most teaching areas (laboratories and seminar rooms) were assigned to the upper floors, while offices area incrusted sporadically as boundaries to step each faculty aside. Lastly research areas and other auxiliary facilities are left in the basements. Furniture and its associated services act as a potential constraint to flexibility. The concept in use is that of horizontal sub-mains. Though allowing rooms on either side of the corridor to be services, it provoked disturbances in the circulation areas (as argued in sect. 3.4.4.1) when repaired or altered. It conveys piped utilities to a system of fixed furniture. This froze the layout of the furniture to one configuration that of a double row of island benches, thus impeding future configurations as needs arose.

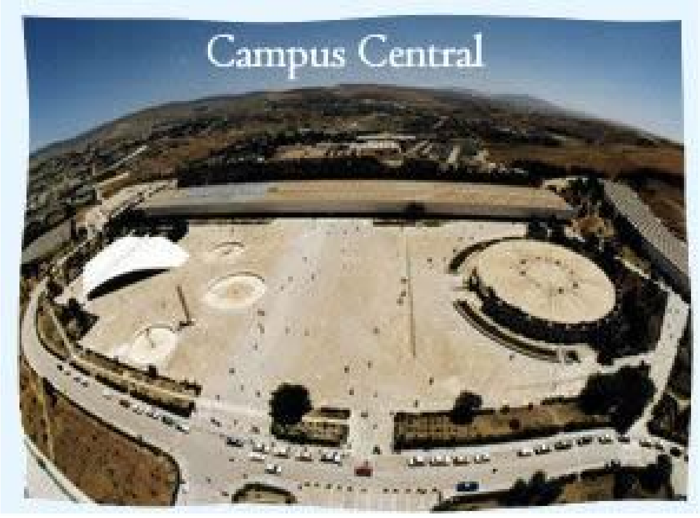
Fixed cupboards were generally located on one side of the laboratories, grouped in pairs. Other items were either stored in local storage (fixed wall shelves, drawers and refrigerators) within the laboratories or in the ancillary spaces for communal use. Tables 5.4.1 and 5.4.2 set out the results of the physical, furniture, and services surveys carried out in the four laboratories visited.

8.5. Assessment of the Planning aspects.

8.5.1. Location.

The physical survey in conjunction with interviews with students and members of staff revealed that the location of the Bloc of laboratories in relation both to the schools within which they are housed and to the campus' other major facilities (restaurant, main library, and Shops) was generally satisfactory. A major reason for the success of their location, as it emerged from interviews, stemmed from the use of a structuring concept (the esplanade) in the planning of the campus. The esplanade is raised as a central focus, giving access to the schools of study and other major university facilities and separating pedestrians from vehicular traffic for safety ease of movement and convenience. On the other hand it created an open and yet massive out door space bringing discomfort under severe climatic conditions. Either in winter or in early spring extensive exposure to winds, rain, sunshine and other disagreement of all kind for is the only or solely route to cross from one bloc to another. This can simply verified in the field in that to make a journey to either the main library or, the main restaurants one ought to go out door.

Figure 8.5.1.A: **Schematic Overall Plan of the Campus**.



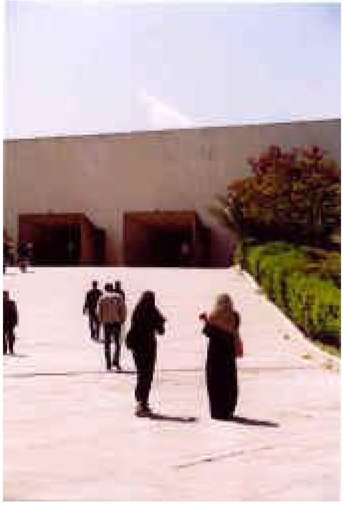
Source: WWW.UMC.dz 2008, (visited September 2008)

Figure 8.5.1. B:

Main Entrance to Science BLOC

Figure 8.5.1. C:

View of the SCIENCE BLOC from above



Source: WWW.UMC.dz 2008, (visited September 2008)

8.5.2. Space Standards.

8.5.2.1. Usable Area Per Student.

The comparison of the figures in Table below point to a big discrepancy between the recommended usable area per student and the one currently is use. A clear mismatch appears between the two figures. In some instances the recommended standard is three and a half times bigger than the one in use. Furthermore, while the recommended standard varies according to the year of the course (sect.3.4.2.1) the one in use varies according to the discipline. When asked whether the allocated area matches the work requirements, the majority of students complained about the exiguity of the premises. The heads of schools noted that causes at the heart of this 'malaise' are twofold. One is the lack of financial resources and the other is the growth of student numbers.

Table 8.5.2.1a:

Comparison of the Recommended Usable Areas per Student With those Currently inUse in the Laboratories.

Discipline 1st & 2sd years honour	Recommended standard (sq. ft)	Standard in Use (sq. ft)	Above/ below recommended standard (sq. ft)
Organic chemistry	45	13.07	Below
Inorganic chemistry	45	12.94	Below
General physics	45	19.62	Below
Electronics	45	20.93	below

Source the Author 2008

Table 8.5.2.1b:

Results of the Physical Survey of the Laboratories.

Disciplines Items	Organic Chemistry	Inorganic Chemistry	General Physics	Electronics
Room code number	NA	NA	NA	NA
Number of Students	40	64	32	20
Length of the room	9.0 (m)	14.4 (m)	10.8 (m)	7.2
Width of the room	5.4 (m)	5.4 (m)	5.4 (m)	5.4 (m)
Area of the room (sq. m)	48.6	77.76	58.6	38.88
Usable area per student (sq. ft)	13.07	12.94	19.62	20.93
Orientation	West	West	East	East
Number of doors	3	4	2	2
Dimensions of doors	1.0 * 2.2 (m)	1.0 * 2.2 (m)	1.25 * 2.2 (m)	1.25 * 2.2 (m)
Number of windows per module	2	2	Either 1 large or 2 smalls	2
Structural bays (m)	3.6 * 5.4	3.6 * 5.4	3.6 * 5.4	3.6 * 5.4

Source the Author 2008

8.5.2.2. The Height of Laboratories.

Arguably one can induce from table 8.5.2.3 bellow that there does seem to be a match between the recommended height and the one in use. Interviews asserted the general acceptance of a 3.0 m laboratory height.

8.5.2.3. The Planning Module.

According to the table referred to bellow, the planning module used complies with the recommended basic planning module.

Table 8.5.2.3.

Comparison of the Grid Dimensions With Those In Current Use in Laboratories.

Grid Dimension	Standard in Use (m)	Recommended Standard (m)	Above/ Below Recommended Standard (m)
Length	**Org. Che: 9.0**	**Basic Planning dimension Of 3.0**	**Match**
	Ino. Che: 14.4		**Match**
	Gen. Phy: 10.8		**Match**
	Electron: 7.2		**Match**
Width	**5.4 for all labs**	**Ibid**	**Match**
Height	**3.0 for all labs**	**3.0**	**Match**
Module	**3.6 * 5.4**	**Basic module of 3.6* 3.6**	**Match**

Source the Author 2008

8.6. Assessment of Furniture and Equipment in the Laboratories.

8.6.1. Furniture.

8.6.1.1. The Bench Requirements

The type of bench used in the all laboratories is the fixed double row island. Its dimensions are 3.6m * 0.8m. In contrast to the criteria regulating the provision of benches Laboratory benches, which stipulates that i) movable furniture should be preferred to fixed ones, and ii) anthropometric constraints govern the bench dimensions, the type and dimensions in use in the all cases studied did not take account of these two requisites. These choices, explained by the estates officer, caused many defects. In particular, it made flexibility of use virtually impossible.

8.6.1.1.1. The Width of the Bench.

The furniture survey showed that the width of the double row island bench was 0.8m. However, in the British Standards Regulations, the width for a single sided bench is 2ft. (0.61 m). At first one is tempted to think that a double row should therefore require at least twice the single's width. Yet the users' survey suggested that 1.0 m could meet the requirements of the work. Thus, though the width in use is lower than it should be it need not equal twice the single one.

8.6.1.1.2. The Height of the Bench.

The proposed bench height in all instances is 0.8 m. According to Table 8.6.1.1below it seems that i) there exists a mis-match between the recommended height and the one in use and ii) while the Table points to clear anthropometric constraints which regulate the height of the bench, the standard in use seems to have taken no account of this. However, students' response to a question about whether a bench height of 0.8 m strains their back was that most of them found it reasonably satisfactory.

8.5.1.1.3. Gangways.

Table 8.6.1.1. Shows that gangways (spacing between benches) are generally inadequate. These vary from 0.83 m, the lowest, (in the organic chemistry laboratory) to 1.16 m, the highest, (in the general physics laboratory). The survey noted that over-provision of benches, inherent to growth in student group sizes subsequently to overall students population growth, has had profound repercussions on the laboratory area, constraining both convenience and safety at work.

Table 8.6.1.1.:

Comparison of Recommended Bench Dimensions With Those in Current Use in the Laboratories.

Bench features	Standard in Use (m)	Recommended Standard (m)	Above/ Below Recommended Standard (m)
Length	**3.6**	**3.05-3.95**	**Match**
Width	**0.8 (double)**	**0.6 (single)**	**Below**
Height	**0.8**	**Sitting: 0.7**	**Above**
		Standing: 0.85-0.	**Below**
Gangways	**Org. Che: 0.8**	**1.8**	**Below**
	Ino. Che: 0.9		**Below**
	Gen. Phy: 1.15		**Below**
	Electro: 1.05		**Below**

Source the Author 2008

Table 8.6.1.2.
Results of the Furniture and Services Surveys of Laboratories Visited.

Discipline Items	Organic Chemistry	Inorganic Chemistry	General Physics	Electronics
Types of bench	Fixed double row island	Fixed double row island	Fixed double island	Fixed double island &
Number of benches	5	8	4	3 doubles & 1 single
Length of bench (m)	3.6	3.6	3.6	3.6
Width of bench (m)	0.8	0.8	0.8	0.8
Height of bench (m)	0.8	0.8	0.8	0.8
Gangway	0.83 (m)	0.88 (m)	1.16 (m)	1.05 (m)
Bench top	Wood	Wood	Wood	Wood
Type of fume cupboards	Fixed	Fixed	/	/
Number of fume cupboards	2 grouped by pair	4 grouped by pair	/	/
Type of storage	Shelves, drawers & fridges	Shelves drawers & fridges	Shelves & drawers	Shelves & drawers
Purpose of storage	Chemicals, spare part & records	Chemicals spare parts & records	Records & spare parts	Records & spare parts
Type of skins	Integrated & isolated	Integrated & isolated	Isolated	/
Material of skins	Ceramic & stainless steel	Ceramic & stainless steel	Stainless steel	/
Services at the bench	H. W / C.W, electricity, gas	H. W / C. W, electricity gas & vacuum	H. W, C.W, electricity	Electricity

Source the Author 2008

Key to Abbreviations:

1. **Org. Che.: Organic chemistry.**
2. **Ino. Che. Inorganic chemistry.**
3. **Gen. Phy.: General physics.**
4. **Electro: Electronics.**

8.6.2. Equipment.

8.6.2.1. Storage.

Means of storing spare parts, chemicals and student records include fixed wall shelves, drawers, cupboards and refrigerators (particularly in chemistry and biology laboratories). The survey observed that most laboratories were well equipped with storage items. It also identified that other necessary pieces of equipment to back up laboratory procedures, and whose location within the laboratory premises could restrain and encumber further its gross area, have been assigned to core rooms for communal use, as indicated in figure 8.6.2.1 respectively

Figure 8.6.2.1.
Storage racks of Chemistry Laboratories Visited.

Source the Author 2008

8.6.2.2. Fume Cupboards.

Apart from the electronics laboratory, laboratories were provided with fume cupboards grouped in pairs. Though the users acknowledged the good performance of the equipment, their permanent link to the fabric gave rise to various criticisms. Members of staff (heads of schools and tutors) claimed that by being rigidly tied to the fabric, fume cupboards acted as a serious constraint for change in use. A further complaint raised by students was about their location. The users felt that concentrating six or eight (in organic and inorganic laboratories was liable to create circulation problems in the laboratory.

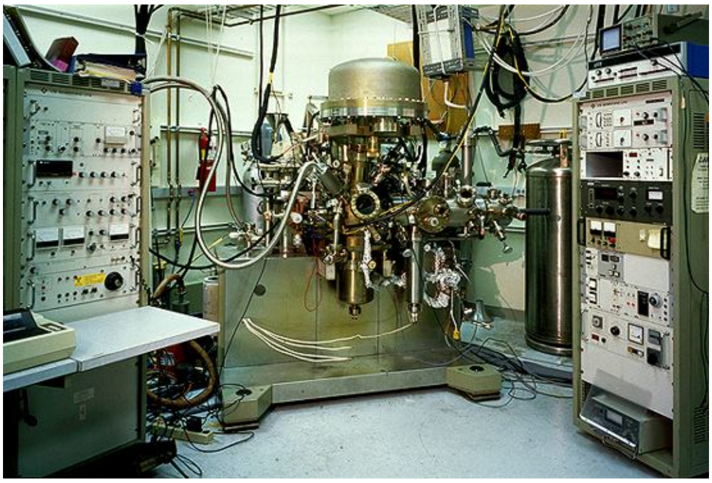
Figure 8.6.2.2.
Fume Hoods of Chemistry Laboratories Visited

Source the Author 2008

8.6.2.3. Other Elements of Equipment.

Isolated stainless steel sinks, chalk boards and pin boards are fixed to the fabric. The users responded positively about these items in relation to their requirements

Figure 8.6.2.3.
Heavily serviced electronic power and supplies



Source the Author 2008

8.6.3. The Services.

The servicing of the four laboratories is achieved by means of horizontal sub-mains which imply that piped utilities are down-fed to benches (8.6.3). Service cores have been planned in each corridor to supply rooms on either side. Technicians and students besides reckoning that repairs to services cause disturbances to neighbouring areas, warned about the danger of having these core services, ‘or cupboards as they are called within the schools’, exposed in the corridor. Vandalism could be the beginning of consequential damage. The other impediment, as the Estates Officer explained, was the fixing of services to the fabric, which contributed to reduction in the potential for flexibility and adaptability. His opinion (the Estates Officer) was that a prime requisite in designing services for a science laboratory is their segregation from the fabric

8.6.4. The Structure.

Though the need to provide for growth and change was explicit in the design brief, its implantation was not obvious. The only element with a potential asset for change and growth was the adoption of a repetitive grid of 3.6m * 5.4m throughout the buildings. However the partitioning system is made up of solid masonry walls, which obstructured further layout configurations implied by the requirements of the work. Heads of schools explained difficulties in obtaining their requests for investment, particularly in terms of demolition costs and furniture removal. The head of the physics school agreed that ‘structural and furniture constraints hindered our requests to proceed for changes in order to improve the method of the physics course’.

8.6.5. Environmental Assessment.

The survey showed that control of environmental conditions within the laboratory confines was necessary. Mechanical extraction and room temperature control were considered critical by most of the users. They proved inadequate, causing discomfort in some places (disagreeable smells and overheating in both chemistry laboratories). All other environmental attributes including daylight, noise and acoustics seemed to have found general acceptance. This was argued by means of a environmental survey conducted by the author all data is encompassed in table 8.6.5 thereafter: Introduction

We have conducted an evaluation of laboratories surveyed to assess how well they perform for those who occupy it. This information will be used to assess areas that need improvement, provide feedback for similar buildings and projects and to help us better manage the environment. Responses were anonymous.

Table 8.6.5.

Environmental Survey of the Laboratories

1. Safety:

1.1 Personal safety: How safe do you feel in the building?
(Please tick)

Unsafe	**1**	[✓ **2**]	**3**	**4**	**5**	**6**	**7**	**Very Safe**

1.3. Access control to parts of laboratory
(Please tick)

Unsafe	**1**	**2**	[✓ **3**]	**4**	**5**	**6**	**7**	**Very Safe**

2 Air quality

2.1. Does the quality of the air have a negative effect on your work performance?
(Please tick)

Not Significant	**1**	**2**	**3**	**4**	**5**	**6**	[✓ **7**]	Very Significant

2.2. Is the air fresh or stale?
(Please tick)

stale	**1**	**2**	[✓ **3**]	**4**	**5**	**6**	**7**	fresh

2.3. Is the air humid or dry?
(Please tick)

Too humid	**1**	**2**	[✓ **3**]	**4**	**5**	**6**	**7**	**Too hot**

2.4. Do you have control over ventilation?
(Please tick)

No Control	[✓ **1**]	**2**	**3**	**4**	**5**	**6**	**7**	**Full Control**

3. Temperature

3.1. Does the temperature have a negative effect on your work performance?
(Please tick)

Not Significant	**1**	**2**	**3**	**4**	**5**	**6**	[✓ **7**]	Very Significant

3.2. Is the temperature in winter too cold or too hot?
(Please tick)

Too Cold	**1**	**2**	**3**	[✓ **4**]	**5**	**6**	**7**	**Too Hot**

3.3. Is the temperature during the summer too cold or too hot?
(Please tick)

Too Cold	**1**	**2**	**3**	**4**	**5**	[✓ **6**]	**7**	**Too Hot**

4. Noise

4.1. Does the distraction from noise have a negative effect on your work performance?
(Please tick)

Not Significant	**1**	**2**	**3**	**4**	[✓ **5**]	**6**	**7**	Very Significant

4.2. Is there significant distraction from noise outside the space?
(Please tick)

Not Significant	**1**	[✓ **2**]	**3**	**4**	**5**	**6**	**7**	Very Significant

4.3. Is there significant distraction from background noise?
(Please tick)

Not Significant	**1**	**2**	**3**	**4**	[✓ **5**]	**6**	**7**	Very Significant

5. Light

5.1. Does the quality of light have a negative effect on your work performance?
(Please tick)

Not Significant	**1**	**2**	**3**	**4**	**5**	**6**	[✓ **7**]	Very Significant

5.2. Is there too much or too little natural light?
(Please tick)

Too Little	**1**	[✓ **2**]	**3**	**4**	**5**	**6**	**7**	Too much

5.3. Is the sun/natural light too bright?
(Please tick)

Not bright	**1**	[✓ **2**]	**3**	**4**	**5**	**6**	**7**	Too bright

5.4. Is the level of artificial light too high or low?
Please tick)

Too low	**1**	**2**	**3**	**4**	[✓ **5**]	**6**	**7**	Too high

5.5. Is the artificial light to bright?
(Please tick)

Not bright	**1**	**2**	**3**	**4**	[✓ **5**]	**6**	**7**	Too bright

5.6. Are the blinds/shutters effective in blocking out natural light?
(Please tick)

Not effective	**1**	**[✓ 2]**	**3**	**4**	**5**	**6**	**7**	Very effective

5.8 Do you have control over artificial lighting?
(Please tick)

No Control	1	[✓ 2]	3	4	5	6	7	Full Control

Source The author 2008

8.6.6. Assessment of the Potential for Change in the Initial Design.

The surveys (physical, furniture and services) indicated that there was a poor provision of potential for change in the initial design. A mis-match between the concept of planning for change and growth sought for the entire university and its achievement was apparent. In many instances the building stock failed to meet responsively the evolving requirements of the dynamic institution that is a technological university.

According to the survey which dealt with change in the activity, several changes had occurred namely:

1. Change in teaching methods.
2. Change in the material and equipment handled.
3. Changes in the size of the activity both in the number of students and the hours taught.

Users complained about their requests not being fulfilled at once. Furthermore, a tutor said that the concept of ‘multi-disciplinary’ laboratory which was intended to replace the conventional discipline boundaries failed, since the provided laboratories were inadequate for such a procedure. Reasons, as identified in the surveys, were associated with the provision of a fixed hardware system (furniture and some equipment) and the connection of piped services piped utilities to the fabric. The Estates Officer claimed that a much more satisfactory procedure to respond to change in the science areas could be a system of loose furniture.

8.7. Summary

Although the sample of laboratories assessed during the course of this of this case study was small, and thus bound to limit the extent of the evidence derived from it, it has nevertheless given a fruitful insight of the laboratory environment.

As for the first aim of the case study, the physical survey showed that whilst the location, the planning module and the height of the laboratories studied seemed to have found general acceptance and to conform to the standards, the usable area per student as well as some bench measurements appeared to be inadequate in most places visited. The environmental survey, on the other hand, brought to light that fume extractions and room temperature control were liable to create environmental discomfort such as disagreeable smells and over-heating. As far as the second aim is concerned, the users survey indicated that the range of facilities provided as to support laboratories procedures seemed to respond unsatisfactorily to users requirements to a great deal. Finally, the detailed study inferred that a key issue in providing a potential for change in the laboratory environment revolved around the services structure relationship. It was found that the building stock failed in many instances to meet the activity's changing requirements. Further, it was found that the link of the services to the fabric acted as a serious constraint to flexibility and adaptability in use. Furthermore, with the advent of sustainability as a fundamental emerging issue in architecture a more holistic design approach should necessarily be applied in the case of laboratory facility.

8.8. Future Directions

Post-occupancy evaluation is a powerful, though underutilized, tool with which design professionals and behavioural researchers study completed buildings. In its most scientifically rigorous format, post-occupancy evaluation involves systematic evaluation of opinions about buildings from the perspective of the people who use them. It assesses how well buildings match users' needs and identifies ways to improve building design, performance, and fitness for purpose. One might imagine a post-occupancy evaluation of a research facility that looks for evidence that the design influenced the building's use in ways the designers did not intend. Looking ahead, we have identified a preliminary list of topics and directions that architects and neuroscientists—supported by others such as social scientists—might explore together in the near future.

8.8.2. Physical Influences

- What aspects of space design would help researchers to maintain their focus and avoid "cognitive overload"? To what degree does visual clutter in a lab environment hinder one's ability to think clearly or creatively?

- What actually constitutes a (perceived) barrier to easy collaboration between researchers? Is there a measurable difference in the impact of a door that separates/connects two spaces—even if it stands open—versus just an opening in the wall? What about a window between spaces (cognitive proximity versus physical proximity)?

- Does perceived flexibility, as measured by a researcher's sense that he or she can easily modify the research space, make a difference in the ability to do the best work?
- How important is the presence of transition spaces, in which one can maintain a sense of connectedness to the outdoors and thus still feel oriented to external cues?

Possible experimental approaches that could help to answer these questions would involve pairs of actual lab configurations that differ in key characteristics, such as relative openness, transparency to adjacent spaces, or visual distractions. Observation of use patterns, interviews with lab occupants, and other non-invasive surveys would be implemented over extended periods of time.

8.8.3 Behavioural Influences

- To what extent are organizational or institutional culture factors influential in supporting collaboration/collegiality, as opposed to architectural conditions? How much is dependent upon the individuals or the culture of the research entity?
- To what degree does trust (for example, between researchers) enter into the equation? Consider willingness to share equipment, to leave connecting doors open, to store glassware in a semi-public corridor, etc.

These questions probably require more interviews and fewer truly experimental techniques than the first set of questions. Enlisting behavioural psychologists and organizational specialists to help in studying and analyzing these factors would be necessary but could yield critical new information about how space and culture can be combined in better building design. In identifying organizational or cultural factors that impede or encourage interaction, could architectural solutions be devised to specifically alter or support them?

If one accepts the premise that improved collaboration between researchers will more effectively lead to scientific breakthroughs and ultimately benefit humankind, then a logical implication would be that lab design should be optimized to enhance such collaboration. Architects would benefit immeasurably from a more scientific, empirical basis for making design decisions. Neuroscience research has the potential to advise lab designers on, for example, how to minimize the perception that barriers to collaboration exist within a building. The combination of experiments tailored to answer these questions and post-occupancy evaluation of existing research facilities will undoubtedly yield enormously valuable results that can be applied to the building of new research institutes.

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CHAPTER NINE:
CRITERIA AFFECTING THE TRANSFER OF LABORATORY FACILITIES DESIGN REQUIREMENTS TO THE ALGERIAN CONTEXT

9.1. Introduction.

The chief aims of this chapter are to i) examine the extent to which it is possible to extrapolate from international benchmarking laboratory facility design expedients to the Algerian context and ii) scan the potential factors that can be influential in this transfer. In attempting to achieve these goals, one should bear in mind, as stressed in the relevant literature, the danger of ignoring the complexity and associated problems implicit in the transfer process. Implementation of related design concepts from one culture to another regardless of the context in which the transfer is operationalised has shown many defects in the past. Endless instances exemplify this fact e.g. Algiers, Constantine and Oran universities are instances amongst many other in housing, health care facilities, and transport. Rapoport and Watson observed that:

> "Physical determinants such as anthropometrics and ergonomics, as well as comfort needs with regard to light, heat and sound which until recently were considered as hard and quantifiable data are themselves affected by cultural attitudes and social forces prevailing at the time and place of their inception".(1)

Further to Rapoport and Watson's warning about the fallacy of the 'average man concept' (2), Dandy argued that a sensitive understanding of climate is an essential requisite in the design of science buildings in countries ranked under the heading of hot or dry climates.(3) Additionally, two more key factors involved in the transfer process were identified by the U.N.E.S.C.O. works in the field of higher education in Third World countries. These are the availability of resources (e.g. building materials, skills, technology and financial resources) and the organisational aspects associated with architectural design.(4)

9.2. The Fallacy of the Average Man Concept.

For a while ergonomics seemed to have found world-wide acceptance. The fallacy of the assumption underlying this state of affairs stems from the unrecognised variability in human physical standards. At present, evidence deriving from both theoretical and empirical research showed the falsehood of generalising such attitude. These studies recognise a stringent match to user's requirements if stress and strain at work are to be avoided. The magnitude of the problem takes an ample dimension when applying blindly one country's design related concepts and standards to another. Pheasant argued that 'the effects can be profound for the people involved in the use of an object which is a part and parcel of an industrialised society' e.g. in the present case from England to Algeria.(5) He (Pheasant) further postulated that the relationship between human activity and spaces is controlled by human physical and environmental requirements. This brings to light that designing ergonomically equates considering closely user requirements in the provision of respective environments.

9.2.1. Human Measurement Constraints.

One of the most important canons of the functionalist theory is the 'Modular'. It is defined as a harmonious measure to human scale, university applicable to architecture and mechanics. This element, which consisted of a relationship between the average size of the human body and human activity, has been central in the development of modern architecture which was reflected by the works of its pacesetters such as the Bauhaus School and Le Corbusier. (6) The development, however, of an empirical science of anthropometry showed the limits of such an approach. It demonstrated that: i) there were variations in size and body shape within the same culture, ii) anthropometric data consists of two types: static and dynamic and iii) anthropometric data gathering is often of a selected sample for a specific purpose and thus bound to be limited in relevance.(7) (8)

Not surprisingly recent developments in ergonomics suggest a divorce from purely functionalist theories, which over-rated human body dimensions in relation to other user requirements. At present, there seems to be a growing tendency towards a comprehensive user-centred approach to design, which derives its fundamental principles from Vitruvius's philosophy of design. This calls for an inter-relationship between the three major criteria, that of Utilitas, Firmitas and Venustas and thus reconciliation between all aspects of user requirements.

Furthermore, biologists have come up with statistical evidence that anthropometric measurements of human beings change over a period of time. Tanner (1962, 1978), Meridth (1976) and Roche (1979) concluded that in virtually all European countries over a period of 80 years 'biological changes have been occurring'.(9)(10)(11)(12) Pheasant ranked the magnitude of these changes as follows:

15 mm per decade in stature at 5-7 years of age.
20 mm per decade in stature at adolescence.
10 mm per decade in stature at adulthood. (13)

Additionally Roche noted that by contrast with European countries there has been a decrease in the stature of the population of Third World countries.(14) Though various hypotheses have been put forward to explain this phenomena, there does seem to exist a general consensus about the chief causes behind it. These are nutrition, hygiene and health factors.

It has been shown in chapter three (sect. 3.4.2.3 and sect. 3.4.3.1) that there are anthropometric constraints which regulate some aspects of the laboratory environment e.g. the planning module and bench measurements. A comparison of anthropometric measurements of Average European and Algerian adults (figure 6.2.1. (1), 6.2.1. (ii) And 6.2.1. (iii)) besides indicating noticeable variations between them sustain the case to consider anthropometric measurements contextually rather than universally.

It been could be suggested that anthropometric constraints are an essential requisite to consider in the transfer of international benchmarking of laboratories physical space standards to similar Algerian ones.

9.3. Environmental Constraints.

9.3.1. Noise.

It has been pointed out in chapter three that the degree of quietness required is difficult to assess due to subjective factors such as users susceptibility to noise. It is further claimed that noise requirements seem to be culture related attitudes rather than intimately linked to physical needs. Within this context Hall suggested that tolerance of noise is closely correlated to cultural variability.(15) Rapoport and Watson contended that ‘southern Italians prefer rather high noise levels whereas Germans have stringent requirements for quiet’.(16) This shows that objective criteria with which to measure reverberation time, absorption factor and sound insulation could be impeded since the task of establishing acoustics standards is performed by human beings who are subject to culture influence and individual attitudes and choices at any one time.

It is unfortunate that detailed figures about Algerian university laboratory facilities acoustics requirements are not available to compare them with other benchmarks that the influence of cultural variability upon the tolerance of noise, as argued above, could prove important in setting out noise requirements.

9.3.2. Thermal Comfort.

One of the basic requirements of a design is control over thermal comfort, since temperature coupled with humidity affect humans in many ways e.g. efficiency and Safety at work (sect. 5.6.5) as well as physiological stress. Studies about the extent of the effect of temperature fluctuations upon people showed that i) due to geo-climatic differences there are variations in the perception of thermal comfort from one culture to another. In some places these differences exist even between sub-regions of a same culture. ii) Skilled performance could deteriorate if the effective temperature goes beyond the limits of the comfort zones and iii) there exists a potential for adaptation in human beings. (17)(18)(19) Table 6.2.3 which set out the thermal comfort zones for both British and Algerian people indicates that there exists a sensible difference.

These thermal comfort zones can be subject to alterations since as Hawkes argues, buildings have become increasingly artificial. The 'benefits' of air conditioning amongst other environmental features seem to have found general acceptance.(20) Factors believed to have contributed to the change in attitude are mainly the availability of technology and the level of living standards.

The array of differences indicated above suggests that there exists variability in the concept of thermal comfort. An account exemplified of these differences seems rather important in a transfer of building specifications; In the forgoing argument we assessed randomly though this very difference between England and Algeria, for the overall heat load equation embraces an external stimulus (climatic determinants), individual variability and choice of building materials. Hence, English requirements in relation to thermal comfort can only act as a source of ideas; a blind extrapolation could lead to adverse effects.

Table 9.3.2

Comparison between British and Algerian Thermal Comfort Zones.

Type of Work	**Average (C)**		**Summer (C)**		**Winter (C)**	
	G.B	**ALG.**	**G.B**	**ALG.**	**G.B**	**ALG.**
Sedentary Work	**18**	**20**	**15**	**21**	**20**	**22**
Light work: laboratory work.	**15**	**18**	**15**	**20**	**18**	**21**
Heavy work: Mines work: Mines, etc.	**12.8**	**15**	**12.8**	**17**	**15**	**18**

Keys to the table:
* G.B: Great Britain.
* ALG: Algeria.

Sources: Rapport A. and Watson N., 'Cultural Variability in Physical Standards', Transactions of the Bartlett Society, (U.C.L., School of the Environmental Studies, 1967), Vol.6, p.74.
The Middle East and North Africa 1988, Algeria, (London, Europa Publications Ltd., 1988), p.268.

9.3.3 Lighting Constraints.

The nature of scientific activity, as shown in paragraph 3.4.5.2, relies on visual observation and good seeing conditions and thus lighting can influence the efficiency of the performed activity. In England daylight standards have been given a significant importance after the Second World War. Laboratory designers have to conform to a statutory standard of a minimum of 4% of outdoor illumination. Hopkinson and Petherbridge argued that the outdoor conditions of in Europe in general were preponderant in the determination of the daylight factor. (21) They further claimed that there were cultural determinants which influence decisions relevant to daylight specifications. They stated that:

"if the current fashion is for 'picture windows' and for seeking after an outdoor life, the standard of daylight considered necessary for amenity will be higher than in a society which considers the outdoor elements to be cruel and inimical to human beings".(22)

This statement embodies the assumption that the combination of an outdoor-centred life with the tendency to have picture windows' results in a higher daylight standard while the opposite may result in a lower standard. Yet there does seem to be a elf-inconsistency within this statement, for i) the severity of the outdoor elements does not justify a lower daylight standard and ii) relating the need for a higher daylight standard to the factors indicated above e.g. that of an outdoor centred life and 'picture windows' while dismissing the effect of geo-climatic conditions as well as the nature of the activity in deriving the required level of daylight appears rather incoherent.

But if geo-climatic differences are an essential key in determining the required level of daylight for a specific activity, the transfer of daylight standards to Algeria appears to be inappropriate and thus calls for an adjustment of the value of the standard in use in to suit Algeria.

9.4. Geo-Climatic Constraints.

A great deal of empirical and theoretical research has been done about how far physiological, physical and architectural aspects of design can be influenced by the climate.(23) (24) It has been established that there exists traditionally a pattern of association between the built environment and climate. This makes clearer the case for designing in relation to climatic stimuli. Climate appears to be a preponderant factor influencing i) the thermo physical behaviour of building materials and ii) some physical characteristics of design such as roof types, ceiling heights, orientation, dimensions of fenestrations, ventilation and lighting.(25)(26) Within the context of laboratory facility design the association of such constraints with those stemming from physical and equipment requirements increases the complexity of providing this type of building, and calls for stringent attention to all these factors to provide an adequate design. Undeniably, several differences exist between international contexts widely taken Algerian geo-climatic conditions.

In Europe and USA, 'the frequency of rainy days and the rarity of spells of summer weather have become proverbial even if they are not entirely born out by statistics'.(27) The overriding variable in classifying regional climatic conditions is the annual rainfall line. Rainfall variation across Europe and USA shows that there exists a considerable difference from north to south. It varies from 120 inches in the Scottish highlands to about 60 inches in the France and as low as 20 inches in south-eastern Greece. Maximum temperature averages fluctuate throughout the year from 16 F in the north to 25 F in the east. In Algeria climatic conditions; unlike those found in Britain vary considerably. The extent of variability increase from north to south. Further, the transition from one climatic region to another in many instances can occur within very short distances.

Algeria combines two readily discernible types of climates: the Mediterranean and the hot dry ones. The Mediterranean climate embraces two sub-climates: the Mediterranean continental and the Mediterranean climate has three broad characteristics: i) concentration of rain in winters and dry summers, ii) warm to hot summers and cool to cold winters, and iii) intensive solar radiation, especially in summer.(28)

Figure 6.3 shows that rainfall varies from 40 inches on the coast to less than 8 inches in the High Plateaux per annum. Most of the rainfall occurs in the period from late September to February. Temperature fluctuations from the north most Algerian coasts to the margin of the High Plateaux are quite noticeable. The Mediterranean marine is characterised by a summer temperature in the range of 25 C to 30 C and by a winter temperature of an average daily minimum of 8C. The Mediterranean continental, on the other hand, is characterised by a summer temperature in the range of 33C to 37C which could rise to 40C in hot days; winter temperatures are of an average minimum of 5C but sub-zero temperatures which result in snow falls occur frequently in the winter.

Along the Mediterranean climate set out above, the hot dry climates expands from the High Plateaux southwards to the southern boundaries of the country. The main features of this climate are aridity, intense solar radiation up to 700 Kcal/ sq. m or 800 Kcal/ sq. m and frequent dust haze and storms. Temperature variations throughout the hot season (from April to September) are within a range of 40C to 50C during day time and room 15C to 25C at night. Rainfall is reduced to less than two Inches per annum. Another significant feature of this type of climate is ‘the sirocco which is a scorching, dry and dusty southerly wind blowing from the Sahara, and it is known locally as the Chehilli’.(29)

It therefore follows that there exists sensible differences between British and Algerian geo-climatic conditions. These differences call for a need to consider local conditions and to apply approaches and architectural solutions appropriate to a specific geographical zone subject to a particular type of climate. Giovanni and Danby argued that dismissing climatic specificities can result in adverse effects in relation to i) human requirements for comfort and ii) certain principles of building design including choice of materials, forms, openings and Orientation.(30)(31) Hence account of geo-climatic constraints is an essential requisite entering in the transfer process. Its centrality emerges further the high capital cost of the provision of science laboratories and thus urges the need for a thoughtful design approach.

9.5. Availability of Resources.

Third World countries, of which Algeria is one, suffer from a chronic shortage of resources. Though there exists a scarcity of capital, major projects (e.g. universities, hospitals, airports, and mosques) are often treated as a matter of prestige rather than in accordance to the country’s true potentialities and realities. This has resulted in many instances in the recourse to foreign financial aid as well as foreign help in physical planning and architectural design. It has been argued in chapter one that the lack of skills in Algeria at all levels and in particular in the field of architectural design has been a critical handicap throughout the independence era. Despite the gigantic efforts deployed in an attempt to alleviate the growing discrepancy between the number of available university places and the demand in the fields of science and technology, an adequate solution has yet to be found. A key reason believed to have contributed to the persistence of this state of affairs is associated to the persistence of this state of affairs is associated with Algeria’s recourse to the technology of the industrialised nations. Until recently, universities, amongst other architectural projects, were planned and designed in conformity with models developed in the industrialised countries with little regard for climatic conditions and local resources. Oran and Constantine Universities are cases in point. After completion of both facilities Algeria faced arduous problems of maintenance, repair and running costs; ultimately they become a real financial burden for the country. Additionally, besides the implicit high costs when applying high technology, Schumacher and Stewart emphasised two more dangers that could face developing countries: i)the danger of unemployment since high technology methods rely mostly on mechanised labour rather on human ones and ii) high priced products are in contradiction with developing countries' low income.(32)(33)

Chapter one highlighted that a vast expenditure on university buildings has been allocated in Algeria. Given the difficulties and constraints it appears crucial to find practical solutions that can be applied whilst fitting into the existing potential resources. Mills and Kaylor argued that the choice of appropriate building materials and technique can have a considerable influence on the efficiency of a building.(34) Vetter claimed further that in the case of complex buildings e.g. universities and hospitals, the implications of a bad choice could be far reaching.(35) These difficulties, argues Danby can be accentuated 'if the initial design assumes an unrealistic level of supporting infrastructures and services which are often unreliable and skills which are particularly scare at technician level'.(36)

Spence and Cook argued that the choice of appropriate technology tends to create a bias in favour of the selection of certain techniques to the detriment of others and that 'some different techniques would, in fact, be better and that efforts to introduce it or develop it would be worthwhile in the long run'.(37) It is further argued that a wide range of building technique alternatives can prove useful to support decisions relevant to the choice of technology. To help carry out this procedure Schumacher reckons the centrality of classifying technology, for it is crucial in developing countries to determine with reasonable accuracy the total amount of capital investment.(38) Accordingly, Spence and cook suggested three broad levels of technology: low, intermediate and high.(39)

Low technology is often equated with inefficiency, cheapness of establishment and poor quality of the products. High technology, on the other hand, calls for enormous capital investment, produce highly refined but expensive goods and can often only be suitable for mega-scale projects. Finally, intermediate technology, is considered as the reconciliation between both ends of the technology scale. Spence and Cook argued that:

"It is possible to identify a middle level, with a higher level of capital investment than that of traditional technologies, but substantially lower than that of the current technologies of the developed countries". (40)

Though the workability of this idea has yet to be evaluated, its advantage, as they (Spence and Cook) further claimed, lies in assisting 'to avoid casting an implication of inappropriateness on all traditional Technologies and on all high technologies, which certainly have their private place'.(41) Schumacher postulated three broad criteria with which to define intermediate technology. These were cheapness, scale and simplicity.(42) Advocating this level of technology, Nyerere argues, could prove beneficial since it can reduce reliance on foreign resources.(43)

In view of the problems discussed above of which choice of technology, operating costs, availability of materials and skills are among the most acute, it appears essential to consider their inclusion in the transfer process of one country's design related concepts to another particularly when the discrepancy between the countries involved is big as it is between England and Algeria.

9.6. Organisational Aspects.

On the international level federal agency and private institutions collaborate actively in partnership and are held responsible for the provision of guidance about all aspects in connection with the design of laboratory facility. For instance the laboratory 21St with its two branch the British and the US A give technical accountancy together with benchmarking to government ministries whenever need? More over them undertake on regular basis research and developments in the field of laboratory facility. System of appraisals backs up the research being done on the subject. Knowledge gained from feedback and through experience is frequently incorporated into new designs. Efforts are made to try to ensure that guidance is constantly kept updated to face up to the complexity and factors involved in laboratory facility design.

In Algeria, on the other hand, it is the Architecture Branch of the M.E.R.S which issues guidance for university buildings. As argued in paragraphs 1.6 and 1.7.2 the paucity and inadequacy of information included in the guidance can hardly monitor the design of this building type. Furthermore, there exist no evaluation studies that could update the appropriateness of the data in use. In the most favourable cases, information contained in the guidance was derived from previous studies (in the early 1970s) done by foreign firms, regardless of what has been achieved in the field as well as of the availability of potential resources.

These differences tend to suggest that the choice for or against implementing the international benchmarking for a laboratory facility model with all its associated facilities can be a determining factor in the success of the design of similar facilities in Algeria. This tend to show, as the U.N.E.S.C.O work demonstrated in principle, that it would be more convenient and rational to seek solutions that take account of the reality with its full dimensions e.g. local needs and construction possibilities. Potential strategies postulated to meet responsively the needs in developing countries in the long run call for an urgent establishment of multidisciplinary groups whose tasks would revolve around carrying out i) surveys of available materials, as well as building industries and skills, and ii) feasibility studies in relation to cost effectiveness, the use of imported technology and regional specifities e.g. architectural form and climatic conditions. Meanwhile, given the pressure to find immediate solutions, studies connected with the problem of the transfer of design related concepts from industrialized countries (e.g. England) to a developing country (e.g. Algeria) recommend the following strategies: i) the use of appropriate standardisation and dimensional co-ordination, ii) appropriate management techniques, iii) adequate maintenance and iv) availability of space parts. (44) (45)

9.7. Summary.

This chapter has discussed i) the array of factors to be considered in transferring international benchmarks with regard to university laboratories facility design expedients to the Algerian context and ii) how far those design expedients can be applied. There emerged four types of factors which can act as potential constraints. Theses were groups into those claimed as intangible and tangible constraints. The first group includes problems of anthropometrics and of cultural variability. The second group, includes i) geo-climatic conditions, ii) availability of resources and iii) organisational aspects. It was argued that to take account of the differences, inherent to these factors, existing between the two countries (England and Algeria) appears crucial in attempting to effect a transfer, and therefore it would be most useful to consider international experience in the field of laboratory design as a source of reference and guidance, and thus subject to adjustments as to suit the different circumstances and potentialities of Algeria.

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CHAPTER TEN:
CONCLUSION AND RECOMMENDATIONS.

10.1. Introduction.

It has been argued throughout this study that the resurgence of interest about the subject of laboratory design, to improve health, safety and efficiency standards brought to light the complexity of having to design for the needs of an immediate use and yet having to meet responsively the occurrence of change and growth in the laboratory's activity.

The need to provide adequate terms of reference appeared to be an essential requisite in the provision of future Algerian university science teaching laboratories. This study attempted to scan the possibility of extrapolating benchmarks of university laboratory facility related design concepts to the Algerian context in order, to some extent, enhance the quality of the design of these spaces.

10.2. Abridgment: Aims, Research Problem and Methodology.

Evidence stemming from chapter one made the case clear for improving the quality of data embodied in the existing guidance. It was shown that the nature of design guidance in current use can hardly monitor the design of such complex buildings. The conclusions from chapter three and four support the contention that the design of university science teaching laboratory requires the most stringent and diligent control over key issues of the laboratory environment. In Algeria, the association of deficiencies e.g. difficulty of assessing demands adequately, scarcity of reliable evaluation studies and lack of overall resources (building materials and skills), gave rise to an immediate need to formulate adequate design expedients that could control future Algerian university laboratory facilities. As there exists a scarcity of qualitative data to assist architects in designing adequately the laboratory environment, English experience was found relevant. Reasons which have led to confine this study to this country's experience have been discussed in chapter one. Consequently the specific aims selected for this study were:

ix. To identify and examine the extent of relevance of International university science teaching laboratories related design concepts for similar Algerian ones.
x. To suggest suitable design related concepts that could possibly govern future Algerian university science teaching laboratory design.
xi. To assess the relevance of performance based methods to enhance quality of design of university science laboratories.
xii. To assess, by means of a case study, the relevance of yardsticks in current use in measuring the state of fit in the interface user/space of the available building stock.

Whilst the first two aims have been dealt with in chapter two, three four and five the lasting two other aims have profoundly dealt with in the rest of the discourse.

It has been shown that universities provision from 1960 onwards can be grouped into i) small universities with an upper student population of 2,000 and ii) big or major universities tailored upon technological universities with a student capacity from 3,500 to 4,500. The main divisions being technology 2,000, science 1,000 and other subjects 1,000. The latter type of university buildings was found most likely to match the Algerian requirements in terms of size and academic structure. As a result this type was selected as basis for this study. Additionally, it has been discussed that laboratory design is controlled by two main streams of design requisites. These were identifies as those elements that relate to the: i) physical attributes of the laboratory environment including planning module, space standards, furniture and equipment, and ii) environmental features including services piped utilities, lighting, acoustics, safety and noise requirements. It was established that there was a strong pattern of association between the two sets of design requirements set out above and the level of flexibility or adaptability. Further, evidence was released that if a dynamic learning space is to be provided, flexibility and adaptability must be central to the design of university science teaching laboratories.

Accordingly, a whole chapter scanned succinctly these two design concepts, we manifested that ideas about flexibility and adaptability tended to suggest that while their main respective objectives centred around the quality of an object subject to change, highlighted uncertainty and unpredictability as important hallmarks of the situation dealt with. There also emerged that the impetus that gave rise to the incorporation of a potential for change and arose from the recognition that buildings in most rapid flux, such as university laboratory facilities, hospitals and offices, grow, change and become obsolete rapidly. Therefore, understanding the potential causes resulting in change in the laboratory's activity was argued to assist, to a degree, to predict the likelihood, rate and extent of change. Studies featuring the impact of change and growth in the activity's requirements upon the laboratory environment suggested four dominants causal forces: i) the growth in student number change in technology, iii) change in the curricula, and iv) change in the activity's size.

Attempts to postulate potential design strategies for coping with change land marked three broad design approaches: flexibility, long-life loose fit, and scrapping. It has been argued in chapter four that while the first two strategies seemed to have found more acceptances (although both raised criticisms as they induce high and/or subsequent costs) the third one remained largely unsound for reason outlined earlier.

The limited evidence derived from the case study in chapter five (since it was based on a small sample) suggested that i) the relevance of some aspects of the laboratory environments as compared to the standards found in the relevant literature was debatable. Generally the range of facilities provided to support laboratory procedures, e.g. fume cupboards, storage and associated ancillary rooms, was fairly satisfactory. Iii) although the case study asserted the occurrence of change as a result of the four causal forces outlined above, it showed that there was a poor provision of a potential for change. Interviews with the users revealed that the association of furniture and services to the fabric in connection with a limited financial budget hindered flexibility and adaptability in use.

While during the course of pursuing the two first aims the need to test the relevance of international benchmarks university laboratory facility related design concepts appeared essential, the evidence emerging from the relevant literature points clearly that there exists a number of constraints that ought to be observed in the transfer process. It has been argued that the array of potential constraints that might be influential in attempting to implement international benchmarks design requisites in Algeria can be grouped into those claimed: i) to be tangible including the geo-climatic conditions, the Availability of resources and the organisational aspects and ii) to be intangible which enclose anthropometrics and cultural variability.

It was finally conclude that international experience in the field of laboratory design can act as valuable source of inspiration and thus liable to necessary adjustments so as to suit different circumstances. To sum up, the evidence stemming from this study tends to suggest that the set out above aims were, to a large extent, achieved. The following accounts which consist of tentative recommendations are the culmination of this work. Theses will be grouped under two major sub-headings: organisational aspects and planning and design recommendations.

10.3. Recommendations.

10.3.1. Organisational Aspects.

It has become obvious for some time now that in this era of rapid sociotechnic advance, if a modern society is to achieve its aims of economic and cultural growth then a fully educated community if necessary. The back bone, it is said, of this enterprise is the provision of higher education training which in turns require adequate facilities. The interface from the review of international experience is that organisational aspects are significantly important means of control over the provision of higher education facilities. In the absence of such structures in Algeria, it is suggested that, similar scientific agencies and governing design laboratories as well as university building officers, should be set up as to form a hierarchical frame by means of which decisions relevant to the planning and design of these buildings can be cautiously carried out.

10.3.2. Evaluation and Feedback Data.

A Flourishing international debate pointed that In England, in USA and others, a system of evaluation backs up research being done about the subject of laboratory design. In Algeria, on the other hand, evidence stemming from chapter one indicated that there was a scarcity of such studies. Further, the survey of relevant literature revealed that post occupancy evaluation has a become a fundamental pillar of modern design. It proved to be a valuable data generator for those involved in architectural design. It therefore ensues that while future Algerian university laboratory design should be subject to appraisals procedures it is also suggested to undertake, in the immediate run, evaluation of the existing building stock so as to illuminate the various shortcomings of previous design. However, as evaluating strategies are of so many types it could also be recommended to carry out an investigation in order to establish i) an appropriate evaluation method of Algerian university science teaching laboratories and ii) ways of achieving it.

10.3.3. Availability of Resources.

The prevailed discourse demonstrated that the constraint of the availability of resources can be decisive factor in the success of a design. The evidence stemming conjointly from chapter one and six tend to postulate that scanning with reasonable accuracy the nature and availability of resources in terms of building materials, building industries and skills as well as financial resources are essential requisites to consider in the design of future Algerian university science teaching laboratories.

10.4. Planning and Design Recommendations.

Change has become an established objective in the system of architectural design. Analysis of past studies highlighted that a sensitive understanding of potential causes of change in organisation is central in attempting to mitigate its effects on buildings. It emerged that the

10.4.1. Space Standards.

The need to consider closely the relationship between the nature of the activity and the space it occupies is an indisputable goal of architectural design. The identification of benchmarks in relation to laboratory facility related design concepts in association with analysis of some ergonomics studies revealed that there was close association between the laboratory environment and the human body measurements e.g. planning module, laboratory height, and bench measurements. The need to provide adequate space standard emerged as key issue in laboratory design. It is therefore recommended to include anthropometrics in the equation of future Algerian laboratory facility space calculations.

10.4. 2. Services and structure.

The evidence emerging from chapter three and five suggest that services should as far as possible segregated from the laboratory fabric as their connection proved to hinder dramatically further use of the premises. It is therefore recommended that this fundamental principle of laboratory design should be considered in similar Algerian ones.

10.4. 3. Flexibility.

Whilst both flexibility and long-life loose-fit approaches were argued to have found some assent, scrapping remained a bold claim. Among the concepts developed to achieve these strategies are the shell and neutrality concepts. These seemed to match most the Algerian situation, since both over-provision and scrapping were argued to be accompanied by financial penalties. Thus, a combination of the shell principle (which stipulates the distinction between those that are time-independent) with the neutrality concept (which calls for increasing or decreasing similarity between the various components of a building) could be recommended as a suitable means with which to respond, to a certain extent, open-endedly to change and uncertainty in future Algerian university science teaching laboratory design.

Laboratory Sample of Flexible learning
Group size: 24-30 / Computer: 12- 15 / Sinks 12 Worktop 27 m2 / Storage 14 m2

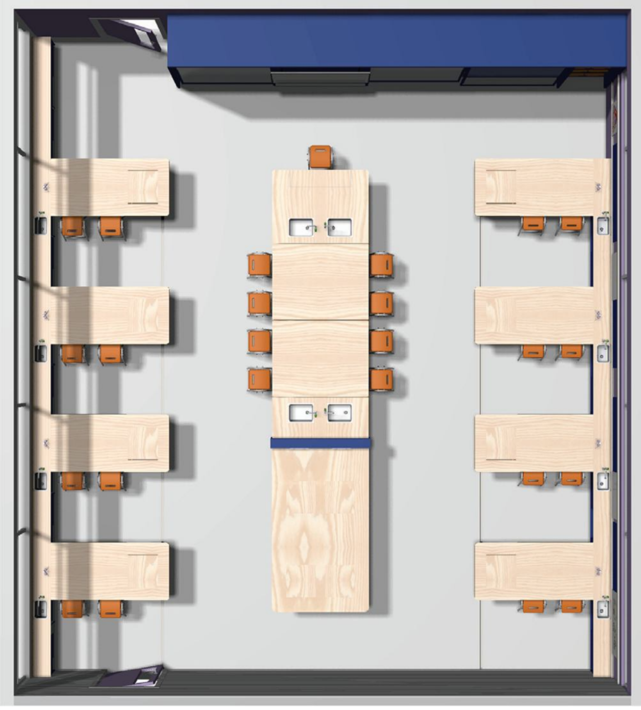
Source: Laboratory 21st, Concepts and proposals, April 2006

Flexible learning

Source: Laboratory 21st, Concepts and proposals, April 2006

Flexible learning

Source: Laboratory 21st, Concepts and proposals, April 2006



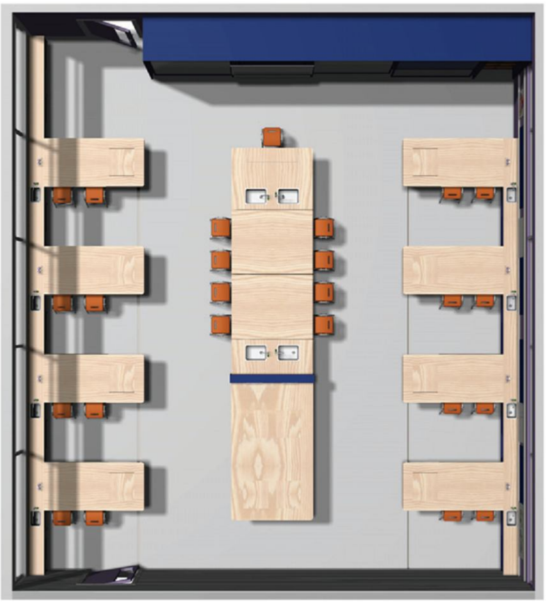
Source: Laboratory 21st, Concepts and proposals, April 2006

Source: Laboratory 21st, Concepts and proposals, April 2006

Source: Laboratory 21st, Concepts and proposals, April 2006

Practical Mode Group Discussion

In practical mode each group is
Served by the 8 perimeter sinks
And by 4 of the double gas
outlets. In the centre of the
Room 4 students are located at
The bottom end of the central
Island giving 2 groups of 4



Source: Laboratory 21st, Concepts and proposals, April 2006

Group Discussion

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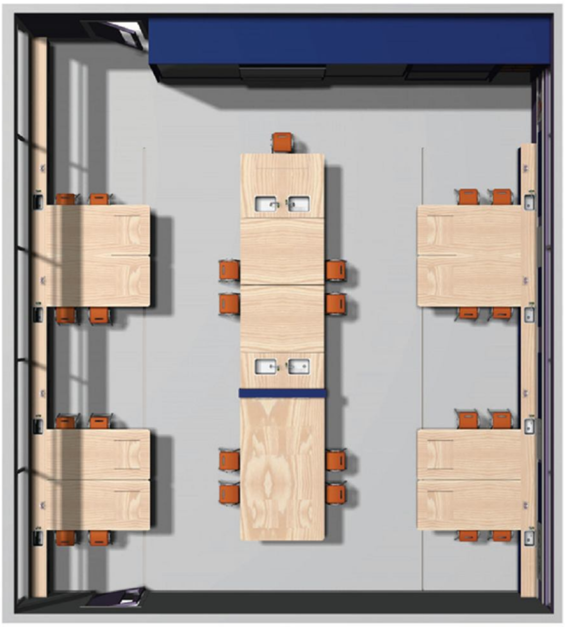

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Source: Laboratory 21st, Concepts and proposals, April 2006

Role Play

On the wall with the display boards the perimeter benches are moved to the ends of the room to create a large gathering area. The teacher can use this area to encourage role play activities etc. It can also be used as a demonstration area by using posters or whiteboards located on the wall rails. Pupils gather around this space and they can also sit at the opposite end of the central island.

POTENTIAL LOCATION OF FUME HOODS

Source: Laboratory 21st, Concepts and proposals, April 2006

Disabled Work Bench

Source: Laboratory 21st, Concepts and proposals, April 2006

Disabled Access

Students with disabilities can be Seated at the top of the laboratory at A specially configured table. This is a Change from previous building handbook suggestions which placed special needs students around the perimeter benching of the laboratory (see appendices p.43). This allows the students to have an active role within the class. Electricity and gas is supplied from nearby fixed furniture. The sink is fixed to the height adjustable table with waste exiting via a flexible hose which connects directly to a nearby sink. Connections are made with quick release fittings which allows the tables to be reconfigured for other laboratory activities.

Waste outlet
Height adjustable surface
400 x 300 sink
Flexible hose
Cantilevered work surface
Electricity and gas outlets
Water in

Source: Laboratory 21st, Concepts and proposals, April 2006

10.5. Further Research.

This study gave rise to a number of areas that need further investigation in order to compile adequate terms of reference to assist enhancing the quality of Algerian university laboratory facilities tentative recommendations have been made with regard to the implementation of some aspects of English university science teaching laboratory design to Algeria. The array of the following topics suggests further detailed study.

I. To assess the extent of the suitability benchmarks laboratory design related concepts in the Algerian context.
II. To assess the appropriateness of the recommended organisational structure as means of control over the provision and source of guidance about university facilities.
III. To evaluate the potential of accommodating change with respect to the existing stock of universities in general and of laboratories in specific.
IV. To assess the extent of feasibility of the combination of the shell and neutrality concepts as potential ways to achieve flexibility in the context of Algerian university science teaching laboratory design.

10.6. General Conclusion.

“All individuals have a right to a quality educational facility, a physical space that supports multiple and diverse teaching and learning programmes and pedagogies, including current technologies; one that demonstrates optimal, cost-effective building performance and operation over time; one that respects and is in harmony with the environment; and one that encourages social participation, providing a healthy, comfortable, safe, secure and stimulating setting for its occupants.”

The overriding objective of this study was to gain from the international experience some reliable information in the field of laboratory design, so as to assist enhancing the quality of design of similar buildings in Algeria. The evidence has shown that the paucity and inadequacy of the design guidance in current use can hardly monitor the design of appropriate university buildings in general or that of science laboratories in particular. The need to bridge the various gaps found in the guidance was apparent. Within the context of this limited study, the intention was not to achieve a comprehensive and exhaustive set of prescriptions but to i) help ease understanding the problems involved in laboratory design and ii) to raise awareness that ‘through seeking we may learn and know things better’. Recommendations were drawn up as to possibly enhance the quality of Algerian university laboratory faculties design.

APPENDICES

APPENDIX A

A/1

Design Guidance (Programme de Realisation) for Algerian university buildings (4000 students)

1. Main Academic Divisions.

1.1. Pure and Applied sciences: 2500 students.

1.2. Social sciences and Humanities: 1500 Students.

1.3. Total students capacity: 4000 students.

2. Organisational Pattern.

2.1. Institute of Fundamental Sciences.

2.1.1. Department of mathematics.

2.1.2. Department of physics.

2.1.3. Department of chemistry.

2.1.4. Department of technology.

2.1.5. Department of architecture.

2.1.6. Department of geology.

2.2. Institute of Social Sciences and Humanities.

2.2.1. Department of linguistics.

2.2.2. Department of economics and law.

2.2.3.Department of humanities (e.g. sociology, psychology, history and geography).

2.3. Department of Biology.

2.3.1. Department of biological sciences.

2.3.2. Department of ecology.

3. Nomenclature of the University Spaces.

A/1

3.1. Academic Spaces.

Type of space	Number	Area allocated per unit sq. m	Total area allocated sq. m
Large lecture theatres (360 students)	2	379.8	745.8
Medium lecture theatres (130 students)	4	233.28	933.12
Lecture room	8	116.84	931.84
Seminar room (35 student)	72	60	4320
Science laboratories	30	116.48	4193.28
Preparation rooms	30	36	1080
Linguistics laboratories	6	116.48	698.88

Workshops	9	116.48	1048.32
Senior lecturer accommodation	100	8	800
Assistant accommodation	300	4	1200
Local library (institute)	11	250	2750
Central library	1	2904	2904
Total	-	-	21605.24

3.2. Administrative Spaces.

3.2.1. Faculty Offices spaces.

Designation	Area sq.m
Chairman of institute or department	25
Chairman's secretary	12
Deputy Chairman	15
Deputy's secretary	10
Department registry office	50
Deputy finance officer	12
Meeting room	30
Ancillary accommodation (storage and services)	71
Total area per institute	225
Total local administrative area	675

A/1

3.2.2. Central (university) Office spaces.

Type of space	Area sq. m
Dean of university	36
Dean's of secretary	24
Finance officer	80
General university registry	119
Meeting room	60
Archives room	39
Ancillary accommodation (storage & services)	35
Total central administrative area	437

3.3. Communal Spaces.

Type of space	Area allocated sq. m

Computer centre	150
Concert hall (250)	300
General cafeteria	200
Shops	75
Medical centre	30
Sportive facilities	12000
Main restaurant (3500 students)	3500
Total Communal area	16259

A/1

Ancillary Spaces.

Type of space	Area allocated sq. m
General maintenance	200
University press	150
Technical services (spare parts storage, chemicals & explosives, and incinerator).	2000
Total ancillary area	2350

3.5. Summary.

i. Academic spaces total area: 21605.24 sq.m
ii. Local administrative spaces total area: 675 sq.m
iii. Central administrative spaces total area: 437 sq.m
iv. Communal spaces total area: 16259 sq.m
v. Ancillary spaces total area: 2350 sq.m
vi. Students accommodation (200 students): 22000 sq.m
vii. University total built area:

APPENDIX B

B1. Materials Suitability for Laboratory Purposes.

Material	Suitability
Aluminium (anodized)	Only suitable for specific projects.
Glazed fireclay	General purpose use. Moderately inexpensive. Easily damaged and stained.
Chemical stoneware	Suitable for all purposes, highly resistant except to hydrofluoric acid and concentrated alkalis.
Material	Costly in comparison with glazed fireclay
Copper-nickel alloy	Suitable for strong caustic soda, sulphuric acid and salts. Expensive
Lead	Dark rooms, etc, where the sink is integral with the remainder of the bench top. Costly.
P.V.C or P.V.C. lined	A flanged lined outlet is required to provide a continuous lined surface.
Polythene or polythene lined	Polythene dipped only suitable as it tends to shrink from steel container. Robust, easily repaired and kind to glassware. Not suitable for solvents.
Porcelain enamel (pressed steel or cast iron)	Subject to chipping and attack by strong acids. Not recommended.
Stainless steel	Domestic sizes to B.S.1244* may be suitable, but not suitable for hydrochloric and sulphuric acids, etc. Robust and hygienic
Wood, zinc lined	Subject to chemical attack, expensive and suitable only in paint and colour laboratories.

Source: British Standards Institution, B.S, 2005,

B2: Materials for Draining Boards and Suitability for Laboratory Purposes.

Material	Suitability
Asbestos cement and fireclay	Very limited application
Lead	Dark rooms, etc, integral with sink. Costly
Polythene and rigid P.V.C	Obtainable by fabrication. Also available in moulded form. Cheap and easily replaceable. Kind to glassware
Porcelain enamel	Subject to chipping. Not recommended.
Stainless steel	Good quality readily available. Hygienic and robust
Teak	Generally satisfactory but regular waxing is desirable
Glass, annealed or toughened	Moderately costly but easy to install and replace. Not conventional pattern. Substantial thickness recommended to provide rigidity of assembly and strength.

Source: British Standards Institution, 2005

B3: Level of Provision of Services for Specific Scientific Discipline.

All biological categories	Level of Provision
Gravity cold water (Leg)	
Normal Waste (Lwn)	
Compressed air (Gca)	High demand for these services
Inert gases (Gi)	
Air extract (Ge)	
All chemical categories	
Gravity cold water (Leg)	
Normal waste (Lwn)	
Town gas (Ght)	High demand for these services
Inert gases (Gi)	
Air extract (Ge)	
All physical categories	
AC mains electricity (Em)	
DC electricity (Ed)	
Monitor circuit (Ecm)	High demand for these services
Screened circuit (Eca)	
Control circuit (Ecc)	

Source: British Standards Institution, 2005

B4 Units of Measure

A	ampere	mA	milliampere
cd	candela	MCM	thousand circular mils
cm	centimeter	min	minute
cph	changes per hour	MJ	megajoule
dB	decibel	mL	milliliter
Â°C	degrees Celsius	mm	millimeter
g	gram	mm Hg	millimeters of mercury
h	hour	mRem	millirem
Hz	hertz	m/s	meters per second
J	joule	n	nano
Â°K	degrees Kelvin	nm^2	nanometer squared
kg	kilogram	nm^2	net square meter
kHz	kilohertz	Pa	pascal
kJ	kilojoule	%	percent
kPa	kilopascal	ppm	parts per million
kV	kilovolt	rad	Radian
kVA	kilovolt-ampere	rpm	revolutions per minute

kW	kilowatt	s	Second
kWh	kilowatt hour	V	Volt
L	liter	VA	volt-ampere
L/s	liters per second	W	Watt
LPM	liters per minute		
LPW	lumens per watt		
lux	lux		
m	meter		
m^2	square meter		

B.4. Power loads & Ventilation

Space	**Task Lighting (W/person)**	**Room Lighting (W/nm^2)**
Laboratories	**250**	**32**
Offices	250	32
Corridors	**NA**	**11**

Space	**Ventilation Air**
Laboratory/laboratory support	6 air changes per hour minimum
Office/administrator support	9 L/s per person minimum

Load	**W/m^2**
Lighting	27-38
Receptacle	48-215
HVAC	97-108
Lab equipment	43-86
Elevators	11-16
Miscellaneous	11-22
Total Range	**237-485**

B.5. Gross and Net Area Calculations

B.5.1..Gross Area

The gross area includes the total floor area of all floors including basements, mezzanines, penthouses, mechanical, electrical, and communications spaces, bench spacing (see bew figure), and enclosed loading docks. Gross area is measured from the exterior surfaces of all enclosing walls, except where the exterior wall surface overhangs the exterior window surface by 300 mm or more. In this case, the gross area is measured from a point one-half the distance between the exterior plane of the window glazing and the outermost plane of the wall. Disregard architectural projections such as cornices and buttresses, and roof overhangs less than 300 mm. The average distance from the floor to the ceiling is used to determine whether a floor area is included at 100 percent or 50 percent in the gross area.

All areas with a floor-to-ceiling height of 2 134 mm or greater are counted at 100 percent. All areas with a floor-to-ceiling height less than 2 134 mm are counted at one-half of the actual gross area, unless otherwise noted not to be included in the gross area. The following additional spaces are counted at one-half of the actual gross area:

i. Exterior balconies and porches
ii. Covered, but not enclosed, walkways, passageways, ramps, and covered building entrances
iii. Exterior open stairs, whether covered or uncovered

The following areas are not counted in the gross area:

- Crawl spaces or any area with a floor-to-ceiling height of less than 1 220 mm. Crawl spaces in excess of 1 200 mm are not counted in the gross area providing the clear height is the result of the natural site terrain or foundation system. It is expected that the depth of footings, lack of interior finish, and so forth will support the position that this area is used for limited access only and for no other purpose. The height of crawl spaces is the distance between the surface of the earth or mud-slab and the bottom of any framing members. It is expected that girders, pipes, or ducts may occasionally protrude below this height.
- Catwalks providing access to equipment
- Exterior, uncovered, unenclosed terraces, ramps, stoops, or pads
- Open courtyards and plazas
- Utility tunnels
- Cooling towers
- Unroofed exterior equipment enclosures
- Unfinished attics

Shaft-type elements are counted in the gross area for one floor only. These include:

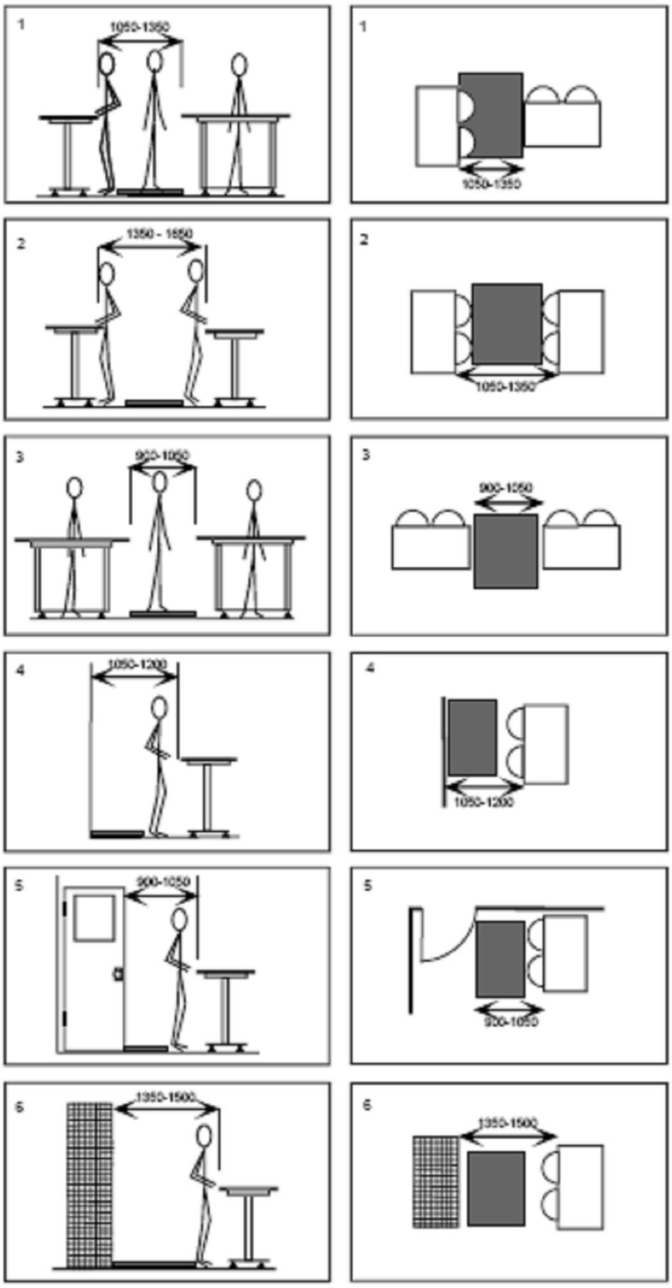
- Atria
- Unenclosed floor openings
- Stairs
- Elevators, escalators, and dumbwaiters
- Mechanical and electrical shafts
- Other shafts connecting two or more floors

Interstitial Distribution Space: Interstitial distribution space, an expansion of the space between the finished ceiling and the underneath side of the floor above used for utility distribution purposes (i.e., ducts, electrical and communications lines, and plumbing) only, is not included in the gross area calculation. Any floor area dedicated to equipment and which provides maintenance access (walk-on deck) within the interstitial distribution space is included in the gross area calculation at 100 percent regardless of the floor-to-ceiling height.

Net Area

The net floor area of a space refers to those portions of the facility available for use for program operations and other necessary support functions. These areas are specifically delineated in the Program of Requirements (e.g., a 12 net square meter office, a 10 net square meter outpatient examination room). The sizes of net areas represented on design drawings or actually constructed are measured from the interior surface of the walls that enclose the space. Exterior walls, interior partitions, columns, structural members, plumbing chases, and internal circulation space for other than individual occupancy are excluded from the net floor area.

Table B.5.1; **Safe spacing between benches**



Source: DfEE, The Stationary Office, Building Bulletin, 1999

APPENDIX C
RECORDING SHEET No.1
Physical Attributes of the Laboratory

Dept. or School: Laboratory Code Number:
Activity: Date of Data Gathering:

1.1. Dimensions :
* Lenght (m) :
* Width (m) :

1.2. Area allocated (sq. m):
1.3. Actual area (sq.m):
1.4. Floor to floor height (m):
1.5. Floor to ceiling height (m):
1.6. Laboratory module (Length*Width) (sq. m):
1.7. Access & usable doors:
1.7.1. Number of usable doors:
1.7.2. Width needed for daily use (person):
1.7.3. Maximum width needed (equipment):
1.7.4. With/without vision panel:
1.8. Windows:
1.8.1. Number of windows per module:
1.8.2. Size of a window:
1.8.3. Type: * Fixed:
* Obscured:
* Sound proof:
* Double glazing:
1.9. Finishes:

	Walls	Ceiling	Floor
washable			
Hosable			
Acoustics			
Insulated			

C/1

APPENDIX C
RECORDING SHEET No.2
Physical Attributes of the Laboratory

Dept. or School: Laboratory Code Number:
Activity: Date of Data Gathering:

1.10. Orientation of the room:
2.1. Benches:
* Single Row Island:
* Double Row Island:
2.1.1. Type: * Single row peninsula:
* Double row peninsula:
* Movable + services spines:
* Movable + perimeter services spines:
* Height (m):
* Width (m):
2.1.2. Dimensions:* Length (m):
* Gangway (m):
* Kneewhole width (m):
2.1.3. Top bench material:
2.2. Storage:
* Shelves:
* Drawers:
2.2.1. Type: * Cupboards:
* Refrigerators:
* Other (specify):
* Spare parts:
* Chemicals:
2.2.2. Purpose: *Records:
* General:
* Other (specify):
2.3. Fittings & Fixtures:
* Plastics (writing):
2.3.2. Boards: * Pin (notice):
*Glass covered pin:
2.3.3. Coat hooks number:
2.3.4. Curtains:
2.3.5. Blackout:
2.4. Fume cupboards Number:

APPENDIX C
RECORDING SHEET No.3
Physical Attributes of the Laboratory

Dept. or School: Laboratory Code Number:
Activity: Date of Data Gathering:

2.4.1. Type: * Fixed to the fabric
* Portable:
2.4.2. Size:
3.1. Number of sinks:
3.1.1. Type:* Incorporated in benches:
* Isolated:
3.2.2. Size:
* Fireclay:
3.1.3. Material: * Stain Steel:
* Ceramic:
* Other (Specify):
3.2. Piped services supplied at the bench scale:
* Cold water (CW):
* Hot water (HW):
* Gas (G):
* Compressed air (CA):
* Vacuum (VA):
* Electricity (E):
* Other (specify):
3.3. Floor drainage:
3.3.1. Drainage from sinks may carry:
* Acid:
* Alkali:
* Solvents:
* Very hot water:
* Other waste (specify)
3.4. Electric power:
* 13a socket (single)
* 13a socket (twin):
3.4.1. Type: * 13a ceiling socket:
* Separate cleaners point:
* Special earth required:
* Other (specify):

APPENDIX C
RECORDING SHEET No.4
Physical Attributes of the Laboratory

Dept. or School:	Laboratory Code Number:
Activity:	Date of Data Gathering:

3.5. Water supplied:

3.5.1. Type:
* Nbr. Of hot taps:
* Nbr. Of cold taps:
* Recalculating cooling:
* Distilled supply:

4.1. Gas:

4.1.1. Type:
* Town gas:
* Other (specify):

4.1.2. Number of outlets:
* Single outlets:
* Twin outlets:

4.2. Steam needed for:
* Autoclaves:
* Cage wash:
* Glass wash:

QUESTIONNAIRE

Dept. or School: Laboratory Code Number:
Activity: Year of Course:
Date of Data Gathering: Information Supplied By:

Part One: Functional Relationships.

1. Number of occupants * Staff:
In the laboratory. * Students:
* Other (specify):

2. Could you please tick the box that best describe the location of your laboratory in the ground floor?
Please tick the relevant box.
* Essential:
* Desirable:
* Unnecessary:

3. Could you please tick the box that describes best the location of your laboratory in an upper floor?
Please tick the relevant box.
* Desirable:
* Acceptable:
* Unacceptable:

4. Essential link to room (s):
1.
2.
3.
4.

5. Proximity desirable to room (s):
1.
2.
3.
4.

6. Incompatible with room (s):
1.
2.
3.
4.

7. Could you please describe the use of your laboratory in any of the following?
Please tick the relevant box (es).
* Single purpose (one activity):
* Multi-purpose (more than one activity):
* Other (please specify):

C/2

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part One : Functional Relationships.

8. Could you please describe the length of time you spend in the laboratory in any of the following:
   * How many hours a day you spend in the laboratory:
   * Maximum number of hours spend in the laboratory:

9. Could you please describe the level of use of the laboratory in any of the following?
   Please tick the relevant box (s).
   * Continuous:
   * Intermittent (used at intervals):
   * Infrequent (little used):

10. Could you please describe which of the following laboratory support facilities is needed to support laboratory procedure?
    Please tick the relevant box (s).
    * Sterilising room:
    * Glass wash:
    * Balance room:
    * Preparation room:
    * Electron Microscope room:
    * Dark room:
    * Cold room or store:
    * Office (tutor):
    * Other (please specify):

11. Is it necessary to have control over environmental conditions within the laboratory?
    Please tick the relevant box.
    * Yes:
    * No:
    If no, please go to question 12.
    If yes, please answer question 11.1 then go to 12.

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part Two: Environmental Conditions.

11.1. Could you please describe what level of control over environmental conditions is required within the laboratory?
Please tick the relevant box (s).

Environmental Conditions	Level required		
	Low	Medium	High
Room temp. control			
Humidity control			
Filtered air supply			
Natural ventilation			
Mechanical extraction			
Fume cupboards			
Daylight for work			
Outlook or view out			
Sunlight			
Blackout			
Artificial lighting			
Colour matching			
Emergency lighting			
Door warning light			
Quiet required			
Security			
Heating			
Other (please specify)			
Other (please specify)			

C/2

Dept.or School:
Activity:
Date of Data Gathering:

Laboratory Code Number:
Year of Course:
Information Supplied By:

Part Two: Environmental Conditions.

12. Could you please describe the level of nuisance created when carrying out your activity within the laboratory?
Please tick the relevant box (s).

Nature of Nuisance	Level of Nuisance			
	Low	Medium	High	None
Noise				
Vibration				
Magnetic field				
Dust				
Radiation				
Infection				
Smell				
Steam (Vapour)				
Noxious				
Heat				
Cold				
Corrosion				
First risk				
Combustible content				
Other (specify)				
Other (specify)				

C/2

Dept.or School:
Laboratory Code Number:
Activity:
Year of Course:
Date of Data Gathering:
Information Supplied By:

Part Three: Change in Activity.

13. Which of the following activities were (are) carried out by you in the laboratory in 1985/1986 and now in 1987/1988.
Please tick the relevant bow (s).

Activities:	1985/1986	1987/1988
* Studying:		
* Teaching:		
* Experiments (Involving equipments):		
* Preparation:		
* Other (please specify):		

14. How was (is) the laboratory occupied in 1985/1986 and now in 1987/1988?
Please tick the relevant box (s).

Was (is) it occupied by:	1985/1986	1987/1988
* Yourself only (full/part-time):		
* Yourself and other staff:		
* Yourself and other students:		
* Other (specify):		

15. Considering all the activities you have carried out in the laboratory since 1985/1986, could you please tick the box (s) that best describes the extent of change in any of the following aspects:
Please tick the relevant box (s).

Change in terms of:	No change	Some	Total Change
• What do you do in the laboratory?			

C/2

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part Three: Change in Activity.

* The information, material and equipment handled:
Continue from question 15.

Change in terms of:	No change	Some	Total Change
* The number of people who Share in your handling of Information & equipment:			
* The ways of handling such Information & equipment:			
* The journeys you make From the laboratory to Other rooms or buildings:			
* Other (please specify)			

16. This question is directed to the teaching staff. Has the teaching carried out by you, changed in any of the following aspects?
Please tick the relevant box (s).
* Year of course you are teaching:
* Type of course (modular, annual, etc.):
* Maximum number of students taught by you:
* Average of hours taught:
* Extent of using illustrative and visual materials.
* Other (please specify):

17. How satisfactory were (& are) the facilities within the laboratory in relation to work?
Please tick the relevant box (s).

	1985/1986	1987/1988
Level of satisfaction:		
* Very satisfaction:		
* Satisfactory:		

C/2

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part three: Change in activity.

* Neither satisfactory nor
Unsatisfactory:
* Unsatisfactory:
* Very unsatisfactory:
* No idea:

18. How satisfactory was (& is) the location of your laboratory in relation to the journeys you made (make) to other rooms or buildings?
Please tick the relevant box (s).

	1985/1986	1987/1988
Level of satisfaction:		
* Very satisfactory:		
* Satisfactory:		
* Neither satisfactory nor unsatisfactory:		
* Unsatisfactory:		
* No idea:		

19. Did you request any change to the laboratory since 1985/1986?
Please tick the relevant box.
* Yes
* No
If no, please go direct to question 20.
If yes, please answer questions 19.1 & 19.2 then go to 21.

19.1. Were the requests made because of the unsuitability of any of the following characteristics of the laboratory to your work?
Please tick the relevant box (s).
* Area of room:
* Visual privacy:
* Acoustic privacy:
* Services:
  - Electricity:
  - Gas:
  - Water:
  - Other:
* Environmental conditions:
  - Lighting:
  - Colour:

C/2

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part Three: Change in Activity.

* Movable furniture:
- * Fixed furniture:
- * Some services:
  - - Electricity:
  - - Gas:
  - - Water:
  - - Others (please specify):

Continue from question 21.

* Environmental conditions:
- - Lighting:
- - Acoustics:
- - Fire safety:
- - Other (please specify):

* Finishes:
* Doors:
* Fenestration:
* Other (please specify):

22. Has the location of the laboratory changed since you first used the building?
Please tick the box if relevant.
* Yes
* No
If no, please go directly to question 23.
If yes, please answer the questions 22.1 & 22.2 then go to 23.

22.1. What was (were) the reason (s) which made you move to a different laboratory?
Please tick the box if relevant.
* Your work has changed:
* A major reallocation of laboratories within the department or the school:
* Effect of alterations and adaptation work on the laboratory:
* Structural failure e.g. collapses of a part of the laboratory:

C/2

Dept.or School:	Laboratory Code Number:
Activity:	Year of Course:
Date of Data Gathering:	Information Supplied By:

Part Three: Change in Activity.
* Other (please specify):

22.2. What change (s) has (have) been made to the laboratory you moved to, so as to be more suitable for you work requirements
Please tick the box if relevant.
* Movable furniture changed/provide
* Fixed furniture installed/removed:

Continue from question 22.2
* Some services (water, gas, etc.) changed/provided:
* False ceiling installed/removed:
* Fixed walls & removable partitions installed/removed:
* Finishes changed:
* Doors provided/blocked:
* Windows provided/blocked:
* No adaptation at all:
* Other (please specify):

23. If the location of your laboratory has not changed, could you please tick the box below which best describes the reason?
* Your work has not changed at all:
* Your work has changed, but your accommodation requirements have not:
* Both your work and the accommodation requirements have changed but an alternative room is not yet available:
* Other (please specify):

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