

**AHP/MAUT-BASED MODEL FOR SELECTING CURTAIN WALL
SYSTEMS IN OFFICE BUILDINGS**

**BY
HAMZA BASEL HAMIDA**

**A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES**

**KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN, SAUDI ARABIA**

**In Partial Fulfillment of the
Requirements for the Degree of**

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

MARCH 2020

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

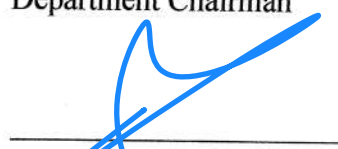
DHAHRAN- 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **HAMZA BASEL HAMIDA** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN CONSTRUCTION ENGINEERING AND MANAGEMENT**.



Dr. Khalaf Al-Ofi
Department Chairman

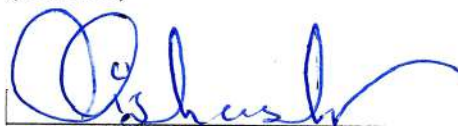

Dr. Salam A. Zummo
Dean of Graduate Studies

23-4-2020

Date



Dr. Adel Alshibani
(Advisor)



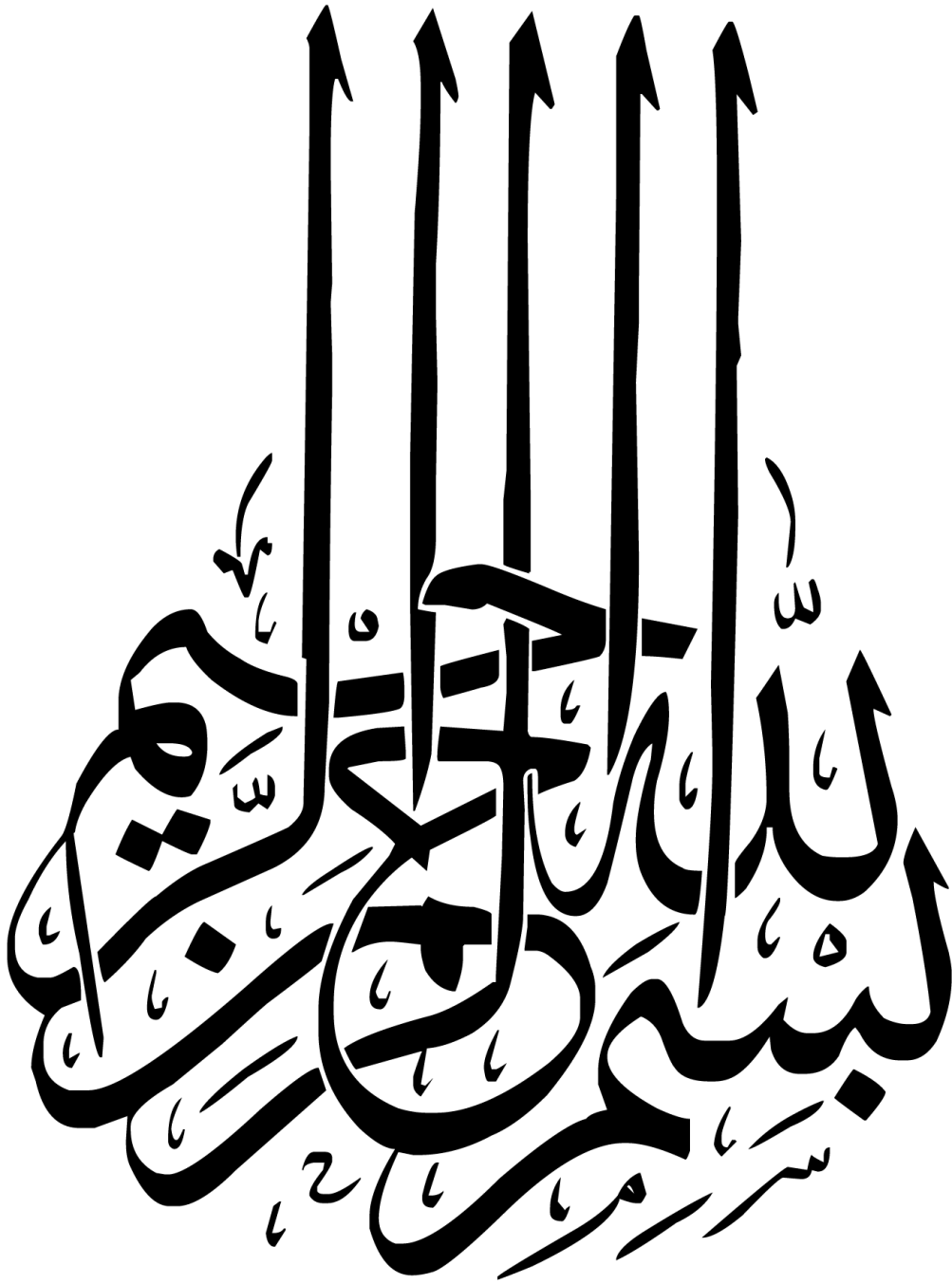
Dr. Ali Shash
(Member)



Dr. Mohammad Hassanain
(Member)

© HAMZA BASEL HAMIDA

2020



IN THE NAME OF ALLAH THE BENEFICENT THE MERCIFUL

قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي
لِلَّهِ رَبِّ الْعَالَمِينَ

وَقُلْ رَبِّ زِدْنِي

MY LORD INCREASE ME IN MY KNOWLEDGE

*To my **parents** and **siblings***

ACKNOWLEDGMENTS

First and foremost, I thank **Allah** for granting me strength, wisdom and confidence to handle and complete this research.

I would like to sincerely express my thanks and gratitude to my advisor **Dr. Adel Alshibani** and to the committee members, **Prof. Ali Shash** and **Prof. Mohammad Hassanain**, for their assistance and guidance throughout my thesis. They provided me the support and encouragement during this research work. I would like to gratefully send my thanks to **King Fahd University of Petroleum and Minerals (KFUPM)** for providing me the opportunity and scholarship during my graduate and undergraduate studies.

I would like to thank my beloved **parents** for their support, motivation and prayers that helped me during my graduate and undergraduate studies. I would like to sincerely express my thanks and gratitude to my beloved brother **Eng. Mohammad Hamida** and my beloved sister **Eng. Amneh Hamida** for standing beside me during this journey. I would like to thank them for their support, assistance, motivation, and sincere feelings.

Special thanks to my friend **Eng. Haitham Alsharif** and my beloved brother **Eng. Adnan Hamida** for standing beside me during the computer implementation phase of this research.

I would like to thank my friend **Eng. Mubarak Al-Dossary** for standing beside me during different stages associated with the data collection.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	VIII
TABLE OF CONTENTS.....	IX
LIST OF TABLES	XIV
LIST OF FIGURES	XXII
LIST OF ABBREVIATIONS.....	XXVI
ABSTRACT.....	XXVIII
ملخص الرسالة.....	XXX
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Statement of Problem	2
1.3 Research Objectives.....	3
1.4 Scope and Limitations	4
1.5 Significance of the Study	4
CHAPTER 2 LITERATURE REVIEW.....	5
2.1 Introduction.....	5

2.2 Building Construction Sector in Saudi Arabia	5
2.2.1 Background.....	5
2.2.2 Future Aspects	8
2.3 Curtain Wall Systems	9
2.3.1 Background about Curtain Walls	9
2.3.2 Metal and Glass Curtain Walls	13
2.3.3 Metal Curtain Walls.....	20
2.3.4 Precast Concrete Curtain Walls	21
2.3.5 Masonry Curtain Walls	25
2.3.6 Stone Curtain Walls	27
2.4 Criteria Influencing the Selection Process of Curtain Wall Systems.....	32
2.4.1 Technical Criteria.....	33
2.4.2 Economic Criteria	39
2.4.3 Socio-Environmental Criteria	42
2.5 Previous Research	55
2.6 Summary.....	58
 CHAPTER 3 RESEARCH METHODOLOGY.....	 60
3.1 Introduction.....	60
3.2 Achievement of the First Objective	60
3.2.1 Literature Review.....	60
3.2.2 Interviews with Local Experts	61
3.3 Achievement of the Second Objective	63
3.3.1 Questionnaire Design.....	63
3.3.2 Pilot-testing of the Questionnaire	75

3.3.3 Data Collection	76
3.3.4 Data Analysis.....	78
3.3.5 Development and Implementation of an MCDM Model	79
3.4 Achievement of the Third Objective	79
3.4.1 Criteria for Selecting the Development Tool	79
3.4.2 System's Architecture.....	80
3.4.3 Data Flow of the Developed Model.....	82
3.4.4 Graphical User Interface (GUI)	84
3.4.5 Model Validation.....	84
3.4.6 Model Limitation.....	85
3.5 Summary	85
 CHAPTER 4 RESULTS AND DISCUSSION.....	 86
4.1 Introduction.....	86
4.2 Respondents' Profile.....	88
4.3 AHP Results	89
4.4 MAUT Results.....	105
4.5 Model Implementation	114
4.6 Computer Implementation.....	121
4.6.1. Overview of the Computer Application.....	121
4.6.2. Validation Results.....	126
4.7 Summary	137
 CHAPTER 5 CONCLUSION AND RECOMMENDATIONS	 138

5.1	Introduction.....	138
5.2	Summary of the Study	138
5.3	Findings.....	139
5.4	Conclusion	140
5.5	Recommendations	142
5.6	Future Research	143
	REFERENCES.	144
	APPENDIX A: DATA COLLECTION LETTER.....	151
	APPENDIX B: UNSTRUCTURED INTERVIEW FORM (ENGLISH)	152
	APPENDIX C: UNSTRUCTURED INTERVIEW FORM (ARABIC).....	153
	APPENDIX D: SUMMARY OF UNSTRUCTURED INTERVIEWS	154
	APPENDIX E: QUESTIONNAIRE SURVEY (ENGLISH).....	157
	APPENDIX F: QUESTIONNAIRE SURVEY (ARABIC).....	173
	APPENDIX G: ANALYSIS OF AHP DATA USING EXPERT CHOICE SOFTWARE	189
	APPENDIX H: CONSISTENT RESPONSES FROM AHP ANALYSIS.....	192

H.1	Consistent results obtained from respondent No. 2	192
H.2	Consistent results obtained from respondent No. 3	196
H.3	Consistent results obtained from respondent No. 4	200
H.4	Consistent results obtained from respondent No. 5	204
H.5	Consistent results obtained from respondent No. 6	208
H.6	Consistent results obtained from respondent No. 7	212
H.7	Consistent results obtained from respondent No. 8	216
H.8	Consistent results obtained from respondent No. 9	220
H.9	Consistent results obtained from respondent No. 10	224
H.10	Consistent results obtained from respondent No. 11	228
H.11	Consistent results obtained from respondent No. 12	232
H.12	Consistent results obtained from respondent No. 13	236
H.13	Consistent results obtained from respondent No. 14	240
APPENDIX I: APPLICATION VIEW CODE		244
APPENDIX J: VALIDATION FORM.....		258
VITAE.....		266

LIST OF TABLES

Table 2.1: Summary of curtain wall materials.....	11
Table 2.2: Criteria involved in the selection process of curtain wall systems (according to the literature)	52
Table 3.1: The scale used in pairwise comparisons	70
Table 3.2: Average random consistency index (RI)	72
Table 3.3: Five-point scale of criteria (SMART).....	75
Table 4.1: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 1.....	91
Table 4.2: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 1.....	91
Table 4.3: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 1.....	92
Table 4.4: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 1	93
Table 4.5: Weight of criteria obtained from respondent No. 1	96
Table 4.6: Weight of criteria according to the AHP section.....	97
Table 4.7: Descending order of technical criteria weights	102
Table 4.8: Descending order of economic criteria weights	102
Table 4.9: Descending order of socio-environmental criteria weights	103
Table 4.10: Descending order of all weights of criteria.....	104
Table 4.11: Utility scores for stick systems	106

Table 4.12: Utility scores for unitized systems.....	107
Table 4.13: Utility scores for unit-and-mullion systems	108
Table 4.14: Utility scores for column-cover and spandrel systems	109
Table 4.15: Utility scores for point-supported glazing systems (Spider System).....	110
Table 4.16: Utility scores for precast concrete cladding panels	111
Table 4.17: Descending order of the fire resistance utility scores	113
Table 4.18: Descending order of the wind resistance utility scores	113
Table 4.19: Descending order of the durability utility scores.....	113
Table 4.20: Evaluation of stick systems	115
Table 4.21: Evaluation of unitized systems	116
Table 4.22: Evaluation of unit-and-mullion systems	117
Table 4.23: Evaluation of column-cover and spandrel systems	118
Table 4.24: Evaluation of point-supported glazing systems (Spider System).....	119
Table 4.25: Evaluation of precast concrete cladding panels.....	120
Table 4.26: Summary of the evaluation of curtain wall alternatives	121
Table 4.27: Evaluation of the stick system by the first interviewee	130
Table 4.28: Evaluation of the unitized system by the first interviewee.....	131
Table 4.29: Evaluation of the stick system by the second interviewee	135
Table 4.30: Evaluation of the precast cladding panels by the second interviewee.....	136
Table D.1: Summary of unstructured interviews.....	154
Table H.1: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 2.....	192

Table H.2: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 2.....	192
Table H.3: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 2.....	193
Table H.4: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 2	194
Table H.5: Weight of criteria obtained from respondent No. 2	195
Table H.6: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 3.....	196
Table H.7: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 3.....	196
Table H.8: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 3.....	197
Table H.9: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 3	198
Table H.10: Weight of criteria obtained from respondent No. 3	199
Table H.11: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 4.....	200
Table H.12: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 4.....	200
Table H.13: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 4.....	201

Table H.14: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 4	202
Table H.15: Weight of criteria obtained from respondent No. 4	203
Table H.16: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 5.....	204
Table H.17: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 5.....	204
Table H.18: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 5.....	205
Table H.19: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 5	206
Table H.20: Weight of criteria obtained from respondent No. 5	207
Table H.21: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 6.....	208
Table H.22: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 6.....	208
Table H.23: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 6.....	209
Table H.24: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 6	210
Table H.25: Weight of criteria obtained from respondent No. 6	211
Table H.26: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 7.....	212

Table H.27: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 7.....	212
Table H.28: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 7.....	213
Table H.29: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 7	214
Table H.30: Weight of criteria obtained from respondent No. 7	215
Table H.31: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 8.....	216
Table H.32: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 8.....	216
Table H.33: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 8.....	217
Table H.34: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 8	218
Table H.35: Weight of criteria obtained from respondent No. 8	219
Table H.36: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 9.....	220
Table H.37: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 9.....	220
Table H.38: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 9.....	221

Table H.39: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 9	222
Table H.40: Weight of criteria obtained from respondent No. 9	223
Table H.41: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 10.....	224
Table H.42: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 10.....	224
Table H.43: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 10.....	225
Table H.44: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 10	226
Table H.45: Weight of criteria obtained from respondent No. 10	227
Table H.46: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 11.....	228
Table H.47: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 11.....	228
Table H.48: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 11.....	229
Table H.49: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 11	230
Table H.50: Weight of criteria obtained from respondent No. 11	231
Table H.51: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 12.....	232

Table H.52: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 12.....	232
Table H.53: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 12.....	233
Table H.54: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 12	234
Table H.55: Weight of criteria obtained from respondent No. 12	235
Table H.56: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 13.....	236
Table H.57: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 13.....	236
Table H.58: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 13.....	237
Table H.59: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 13	238
Table H.60: Weight of criteria obtained from respondent No. 13	239
Table H.61: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 14.....	240
Table H.62: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 14.....	240
Table H.63: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 14.....	241

Table H.64: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 14	242
Table H.65: Weight of criteria obtained from respondent No. 14	243

LIST OF FIGURES

Figure 2.1: Percentages of total building permits issued by all municipalities in 2018	7
Figure 2.2: Percentages of total commercial building permits issued by all municipalities in 2018.....	8
Figure 2.3: Stick System	14
Figure 2.4: Unitized System	15
Figure 2.5: Panel System	16
Figure 2.6: Unit-and-mullion system.....	17
Figure 2.7: Column-cover-and -spandrel system.....	18
Figure 2.8: Spiders fixed to building frames are used in structural standoff systems	20
Figure 2.9: Prefabricated metal panels.....	21
Figure 2.10: Typical architectural wall cladding installation	23
Figure 2.11: Precast concrete wall panels.....	24
Figure 2.12: Masonry veneer curtain wall	26
Figure 2.13: Construction of prefabricated brick panels by masons	27
Figure 2.14: Stone panels mounted on steel sub-frames.....	29
Figure 2.15: Monolithic stone cladding panel	30
Figure 2.16: Stone cladding on steel trusses.....	31
Figure 2.17: Posttensioned limestone spandrel panels	32
Figure 2.18: Stages considered for the determination of embodied energy in building materials	46
Figure 3.1: Summary of research methodology.....	62

Figure 3.2: Utility function	74
Figure 3.3: System Layout.....	81
Figure 3.4: Data flow of the model.....	83
Figure 4.1: Finalized design of the structural hierarchy	87
Figure 4.2: Technical background distribution of the respondents.....	88
Figure 4.3: Distribution of respondents' years of experience	89
Figure 4.4: Spatial distribution of respondents	89
Figure 4.5: Weights of major criteria group and the consistency ratio obtained from the first consistent respondent	94
Figure 4.6: Weights of technical criteria and the consistency ratio obtained from the first consistent respondent	94
Figure 4.7: Weights of economic criteria and the consistency ratio obtained from the first consistent respondent	95
Figure 4.8: Weights of socio-environmental criteria and the consistency ratio obtained from the first consistent respondent.....	95
Figure 4.9: Entry of project information.....	122
Figure 4.10: Description of the evaluation scale	123
Figure 4.11: Evaluation of selected alternatives with respect to technical criteria.....	124
Figure 4.12: Evaluation of selected alternatives with respect to economic criteria.....	124
Figure 4.13: Evaluation of selected alternatives with respect to socio-environmental criteria	125
Figure 4.14: Total scores of alternatives based on the user's evaluation.....	126

Figure 4.15: Evaluation of selected alternatives with respect to technical criteria by the first interviewee	128
Figure 4.16: Evaluation of selected alternatives with respect to economic criteria by the first interviewee	128
Figure 4.17: Evaluation of selected alternatives with respect to socio-environmental criteria by the first interviewee	129
Figure 4.18: Total scores of alternatives based on the first interviewee's evaluation	129
Figure 4.19: Evaluation of selected alternatives with respect to technical criteria by the second interviewee.....	133
Figure 4.20: Evaluation of selected alternatives with respect to economic criteria by the second interviewee.....	133
Figure 4.21: Evaluation of selected alternatives with respect to socio-environmental criteria by the second interviewee.....	134
Figure 4.22: Total scores of alternatives based on the second interviewee's evaluation	134
Figure A.1: Data collection letter.....	151
Figure D.1: Spatial distribution of interviewees	155
Figure D.2: Technical background distribution of the interviewees.....	155
Figure D.3: Distribution of interviewees' years of experience	156
Figure G.1: Structural hierarchy in Expert Choice Software.....	189
Figure G.2: Pairwise comparison matrix of major criteria group in Expert Choice Software.....	190
Figure G.3: Pairwise comparison matrix of technical criteria in Expert Choice Software	190

Figure G.4: Pairwise comparison matrix of economic criteria in Expert Choice Software	191
Figure G.5: Pairwise comparison matrix of socio-environmental criteria in Expert Choice Software	191

LIST OF ABBREVIATIONS

AHP	: Analytic Hierarchy Process
a_{ij}	: The element of the pairwise comparison matrix that is located in row i and columns j
a_{kj}	: The element located in row k of a normalized column j
CI	: Consistency Index
CR	: Consistency Ratio
i	: Row Number
j	: Column Number
MAUT	: Multi-Attribute Utility Theory
MCDM	: Multi-Criteria Decision-Making
n	: Largest Eigen value
n	: The Size of the Pairwise Comparison Matrix that have an n Number of Rows and Columns
n	: The sample size
n	: Number of Criteria
n_0	: The First Sample Size Estimate

N	: The population size
<i>p</i>	: The Characteristic Population to Be Measured in Targeted Populations
<i>q</i>	: 1- <i>p</i> (the completion of <i>p</i>)
RI	: Random Index
SMART	: Simple Multi Attribute Rating Technique
U_C	: Utility score of Criteria obtained from Calculating the Mean of the Responses
<i>U_{MAUT}</i>	: The Utility Score of a Criterion for an Alternative Obtained from the MAUT Section
V	: The Maximum Allowable Standard Error Percentage
<i>W_{AHP}</i>	: The Weight of a Criterion Obtained from the AHP Section
W_c	: AHP Weight of Criteria obtained from Calculating the Mean of the Consistent Responses
<i>w_i</i>	: Eigen Value (Relative Weight) of a Certain Category of Criteria or a Single Criterion in raw <i>i</i>
<i>λ_{max}</i>	: Largest Eigen value

|

ABSTRACT

Full Name : [HAMZA BASEL HAMIDA]
Thesis Title : [AHP/MAUT-BASED MODEL FOR SELECTING CURTAIN
WALL SYSTEMS IN OFFICE BUILDINGS]
Major Field : [CONSTRUCTION ENGINEERING AND MANAGEMENT]
Date of Degree : [MARCH 2020]

The selection of curtain walls plays a vital role in technical, economic, and socio-environmental aspects in office buildings. Furthermore, there are many alternatives of them which can be used in those buildings. Their selection process requires the evaluation of various criteria which makes the selection of the most appropriate wall type a challenging task for decision-makers. Therefore, there is a need for a tool that can assist the decision-makers when dealing with multi-criteria decision-making (MCDM) problems that are associated with the selection of the appropriate wall alternative. This research aims to develop a model that facilitates the selection processes of curtain wall systems utilized in office buildings in the Eastern Province of Saudi Arabia. Accordingly, three objectives were formulated. The first objective is to identify most common alternatives of curtain wall systems utilized in office buildings and their selection criteria. Secondly, a development of an MCDM mode was considered for facilitating the process of evaluating, ranking, and selecting curtain wall systems utilized in office buildings. The final objective is to implement the developed MCDM model in a prototype computer application. The research methodology of this study was designed to achieve the objectives. Based on a comprehensive review of literature, semi-structured interviews with local experts, and pilot study, a total of 23 criteria was found to have an influence in the selection process of curtain

wall systems. Furthermore, total of six curtain walls were identified to be the most common ones used in office buildings. A questionnaire survey consisting of two main sections, AHP and MAUT, was distributed to professionals working in design offices and consulting firms who were involved in the design and selection of curtain wall systems. The results revealed that the fire resistance obtained the highest weight among all criteria. It was found that the precast concrete cladding panels were the best system to be used in office buildings located in the Eastern Province of Saudi Arabia. Angular web framework was used for developing a computer application. The design of the user interface considered different inputs from users which are the project information, numbers and names of the alternatives, and the evaluation of the alternatives with respect all criteria. The model validation reveals that some designers give lower priorities to the detailed work and coordination to be carried out in the job site. The score of any curtain wall system could vary depending on the nature of the project which indicates that assigned score of the system varies based on different experiences and point of views. The validation also incited that some local designers are more aware of the criteria related to construction phase than other performance aspects of wall alternatives. The prioritization of criteria can vary from one practitioner to another. Having a consistent prioritization of criteria can provide a comprehensive checklist for decision-makers during early design stages that facilitates considering different essential criteria for the construction and operation phases of buildings. This can enhance the decision-making process and minimize the subjectivity of the practitioner.

ملخص الرسالة

الاسم الكامل: حمزة باسل حميده

عنوان الرسالة: نموذج قائم على أساس عملية التحليل الهرمي ونظرية المنفعة المتعددة الخصائص لاختيار أنظمة الحوائط الستائرية للمباني المكتبية

التخصص: هندسة وإدارة التشييد

تاريخ الدرجة العلمية: مارس - ٢٠٢٠

يلعب اختيار الحوائط الستائرية دورًا حيويًا في الجوانب الفنية والاقتصادية والاجتماعية والبيئية للمباني المكتبية ، وهناك العديد من بدائل هذه الحوائط التي يمكن استخدامها في المباني المكتبية ، حيث تتطلب عملية الاختيار لتقييم مجموعة من المعايير المختلفة مما يجعل هناك تحديا في عملية اختيار النوع المناسب بالنسبة ، ولذلك فإن هناك حاجة إلى أداة مناسبة بإمكانها مساعدة صناع القرار عند التعامل مع مشكلة صناعة القرار المتعدد المعايير لغرض اختيار نوع الحائط المناسب

تهدف هذه الدراسة إلى تطوير نموذج يسهل عملية اختيار أنظمة الحوائط الستائرية التي تستخدم في المباني المكتبية في المنطقة الشرقية بالمملكة العربية السعودية ، ووفقا لذلك فقد تمت صياغة ثلاثة أهداف رئيسية ، فالهدف الأول هو تحديد بدائل الحوائط الستائرية الأكثر شيوعًا والمستخدمه في المباني المكتبية وكذلك معايير اختيارها، والهدف الثاني هو تطوير نموذج لصناعة القرار المتعدد المعايير والذي يسهل عملية تقييم وترتيب واختيار أنظمة الحوائط الستائرية المستخدمة في المباني المكتبية ، والهدف الثالث والأخير هو تنفيذ هذا النموذج المطور في تطبيق نموذجي على الحاسب الآلي.

تم تصميم المنهجية البحثية لهذه الدراسة بطريقة تساهم في تحقيق هذه الأهداف الثلاث ، فاستنادًا إلى مراجعة أدبية شاملة ، ومقالات شبه منظمة مع خبراء محليين ، و كذلك دراسة تجريبية ، تم العثور على إجمالي 23 معيارًا لهم التأثير في عملية اختيار أنظمة الحوائط الستائرية ، و علاوة على ذلك فقد تم تحديد ستة حوائط ستائرية الأكثر شيوعًا في المباني المكتبية.

تم توزيع استبيان يتكون من قسمين رئيسيين (قسم متعلق بعملية التحليل الهرمي والآخر بنظرية المنفعة المتعددة الخصائص) على المهنيين العاملين بمؤسسات التصميم والاستشارات الهندسية بالمنطقة الشرقية و الذين شاركوا في تصميم واختيار أنظمة الحوائط الستائرية ، و أوضحت نتائج هذا الاستبيان أن مقاومة الحرائق حصلت على أعلى وزن من بين المعايير الأخرى ، كما وجد أن ألواح التكبسية المصنوعة من الخرسانة المسبقة الصب هي أفضل نظام يمكن استخدامه في المباني المكتبية التي تقع في المنطقة الشرقية بالمملكة العربية السعودية.

تم استخدام إطار (Angular web) لتطوير تطبيق الحاسب الآلي لنموذج صناعة القرار المتعدد المعايير المتعلق باختيار أنظمة الحوائط الستائرية المستخدمة في المباني المكتبية ، فقد أخذ تصميم واجهة المستخدم بعين الاعتبار مدخلات مختلفة من المستخدمين وهي معلومات المشروع وأرقام وأسماء البدائل وتقييم البدائل وفقا للمعايير المختلفة ، كشف التحقق من صحة النموذج أن بعض المصممين يقللون من الأولويات المتعلقة بتفاصيل العمل وتنسيقه والذي سيتم تنفيذه في موقع المشروع ، كما وجد أنه يمكن أن تختلف درجة أي نظام حائط ستائري وذلك اعتمادًا على طبيعة المشروع مما يشير إلى أن النتيجة المعينة للنظام تختلف باختلاف التجارب ووجهات النظر ، كما أثارت عملية التحقق

أن بعض المصممين المحليين لديهم وعياً أكثر بالمعايير المتعلقة بمرحلة التشييد مقارنة بالجوانب الأدائية الأخرى لبدائل الحوائط ، فقد يختلف تحديد أولويات المعايير من ممارس لآخر ، و لذلك فإنه من الممكن أن يوفر وجود أولويات متناسقة للمعايير المؤثرة بعملية اختيار أنظمة الحوائط الستائرية قائمة مرجعية شاملة لصناع القرار خلال مراحل التصميم المبكر ، والتي تسهل النظر في المعايير الأساسية المختلفة لمراحل تشييد وتشغيل المباني ، وهذا يمكن أن يعزز عملية صنع القرار ويقلل من ذاتية الممارس.

CHAPTER 1

INTRODUCTION

1.1 Background

Curtain walls are the external walls of buildings that don't carry loads, except their weight and wind loads (Ching, 2014). They are generally thin, lightweight and incombustible panels that contain glass in-fills (Al-Hammad, Hassanain, & Juaim, 2014). They are used in different types of buildings and the major use of them is in office buildings. The Saudi construction sector of buildings is the largest and fastest in the gulf region (O. Alshamrani, Mujeebu, Ashraf, Alghonamy, & Aichouni, 2017). Both of the depletion of energy resources and environmental pollution are influenced significantly by the building sector (O. S. Alshamrani, 2016). The design of the office buildings' envelop configurations that minimizes both of the construction cost and energy consumption is considered to be an optimization problem (Lin, Tsai, Lin, & Yang, 2016). Therefore, the selection of curtain walls plays a vital role in different aspects of buildings which include construction safety, construction duration, construction and maintenance costs, and energy consumption. The literature shows that there are many alternatives of curtain walls that can be used in office buildings and the selection process requires the evaluation of quantitative and qualitative criteria which makes the selection of the most appropriate type of wall a challenging task for decision-makers.

1.2 Statement of Problem

Curtain walls are essential elements for the achievement of the satisfaction of occupants, efficiency of buildings, and economic construction strategies. Their selection process for an office building requires the evaluation of quantitative and qualitative criteria which makes it a challenging task due to the involvement of many parameters and criteria. Unstructured interviews with seven representatives of engineering and architectural design firms in the Eastern Province of Saudi Arabia were conducted to investigate the current practices adopted by local practitioners for selecting curtain wall systems in Saudi Arabia. A general topic was introduced briefly to interviewees and then the interviewees' statements were recorded as illustrated in Appendices B, C, and D (Fellows & Liu, 2015). The interviews revealed that the selection of the curtain wall is relied on the experience of the designers rather than on a systematic approach. Furthermore, it was found that there is no available tool that can be used to assist in the selection process. The subjectivity associated with the architectural considerations, such as the aesthetics and appearance of the system, has a significant impact on the selection process. The economic aspects also are one of the primary considerations that influence the selection process. This can be related to the total cost of the system and its availability in the local market. In addition, the technical performance of the system has an impact on selecting a particular system. It was stated that having the right designer is a key factor for selecting the suitable curtain wall system. Therefore, there is a need for a tool that can assist the decision-makers when dealing with multi-criteria decision-making (MCDM) problems in the selection of the appropriate type of wall in order to avoid subjective decisions. This tool should provide consistent weight of criteria influencing the selection process of curtain walls.

One of the developing aspects in the construction industry is the environmental management which aims to support reducing carbon emissions and also producing sustainable developments. Sustainability is one of the key concepts related to the environmental management (Sherratt & Farrell, 2015). Green buildings are about turning the concepts of sustainability of into the reality. The green building can be defined as “a building that has a substantially reduced impact on the natural environment and that provides indoor conditions conducive to good human health” (Ching & Shapiro, 2014). The Saudi government aims to adopt sustainability and friendly environment concepts on buildings (NIDL, 2017). Therefore, sustainable criteria should be considered in the selection process. These criteria were not considered in the selection process of curtain wall systems in previous studies conducted in Saudi Arabia (Al-Hammad et al., 2014).

1.3 Research Objectives

This research aims to develop a model that facilitates the selection processes of curtain wall systems utilized in office buildings. The developed model will include various criteria influencing the selection process of curtain wall systems. Accordingly, the following objectives were formulated:

1. To identify most common alternatives of curtain wall systems utilized in office buildings and their selection criteria.
2. To develop an MCDM model for evaluating, ranking, and selecting curtain wall systems utilized in office buildings.
3. To implement the developed MCDM model in a prototype computer application.

1.4 Scope and Limitations

1. This study is limited to mid to high rise office buildings.
2. The respondents of distributed surveys are only the representatives of engineering and architectural design firms that were involved in the design and selection of curtain wall systems for office buildings in Saudi Arabia. Due to the time and cost constraints, the respondents will be limited to the Eastern Province of Saudi Arabia.
3. This study is limited to the most common alternatives of curtain wall systems used in Eastern Province of Saudi Arabia.

1.5 Significance of the Study

This study is intended to develop an MCDM model which can assist in the following:

1. Avoiding subjective decision-making in the selection process of curtain wall systems.
2. Providing consistent weight of criteria involved in process of selecting curtain wall systems, including sustainable criteria, according to viewpoint of local experts.
3. Providing decision-makers with a tool that makes the selection process easier and more effective.
4. The model would also be of particular use to decision-makers to improve the performance of new constructed facilities due to the involvement of various criteria.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the building construction sector in Saudi Arabia which includes the categories of building permits, recent statistics, and future aspects. Then a comprehensive review of different curtain wall systems and their selection criteria is presented. Finally, the chapter reviews previous research work conducted on different aspects of wall systems pertaining to the building industry.

2.2 Building Construction Sector in Saudi Arabia

2.2.1 Background

Building permits of construction projects in Saudi Arabia are categorized into six main categories, namely “housing”, “housing, commercial”, “commercial”, “industrial”, “education, health and mosques”, and “social and governmental”. The total permits issued by all municipalities in year 2018 were 88,713 permits. Moreover, the total permits issued in the Eastern Province were 10,278 permits which represent 11.6% of the total building permits in the country. This percentage was the fourth largest one among all of the 13 regions in Saudi Arabia (General Authority for Statistics, 2018). Figure 2.1 illustrates the percentages of the total building permits that were issued by the municipalities in all of the 13 regions in 2018.

The total permits of commercial buildings issued by all municipalities in year 2018 were 3,368 permits. Furthermore, the total permits of those buildings issued in the Eastern Province were 513 permits which represent 15.2% of the total commercial building permits in the country. This percentage was the second largest one among all of the 13 regions in Saudi Arabia (General Authority for Statistics, 2018). Figure 2.2 illustrates the percentages of the total commercial building permits that were issued by the municipalities in all of the 13 regions in 2018.

Office buildings represent a major part of the commercial buildings (Forbes & Ahmed, 2011). They are considered to be the structures in which services are provided, other than structures manufacturing products, selling items, or also structures in which people reside (Downs, 1980). The importance of employees working in such type of buildings is becoming much more than before. The corporate identity (image of a company) is one of the factors intends to improve the performance of employees (Neufert, 2019). The height of office buildings usually range from mid-rise to high-rise. Mid-rise office buildings usually are the ones that have number of floors ranging from 5 to 10 and also provide elevators (Dictionary.com, 2020). Any number of floors higher than this range can be considered as a high-rise office building.

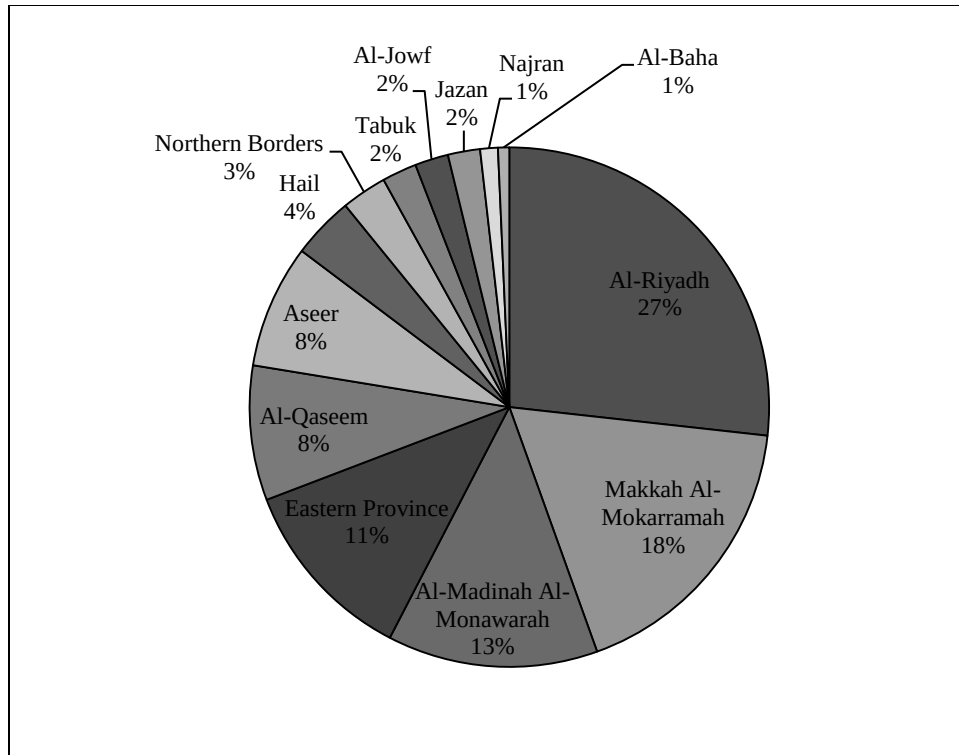


Figure 2.1: Percentages of total building permits issued by all municipalities in 2018

Source: (General Authority for Statistics, 2018)

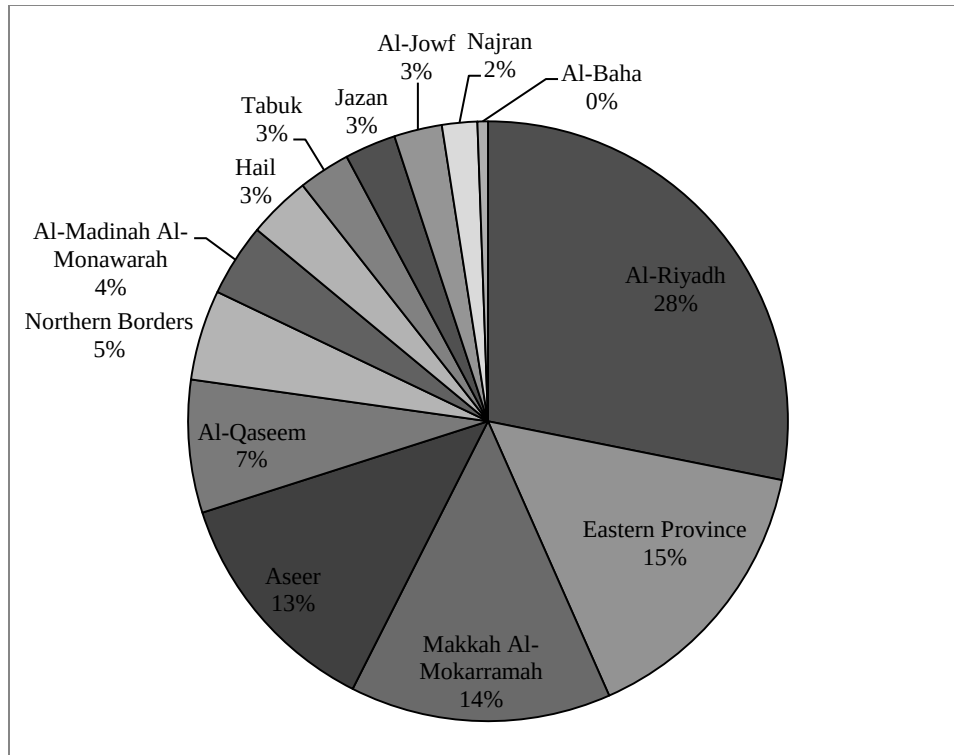


Figure 2.2: Percentages of total commercial building permits issued by all municipalities in 2018

Source: (General Authority for Statistics, 2018)

2.2.2 Future Aspects

The building construction sector experienced significant changes during the last few decades in Saudi Arabia. The developments in the Saudi economy assisted supporting and reviving this sector. However, new challenges are faced by this sector in the present time, which include the need for smart and cost-effective buildings that have limited impacts on the environment. Accordingly, the development of technologies is required for rationalizing the consumption of water and energy and also adopting sustainability and friendly environment concepts on buildings (NIDL, 2017). The adoption of sustainability in the professional practices during design and construction phases generally results in incorporating alternative sustainable materials, such as reusable and recyclable materials (Yates & Castro-Lacouture, 2016). The second theme of the Saudi National

Transformation Program Strategy is the improvement in the living standards and safety. In addition, the second objective of this theme is the improvement of the urban landscape in the Saudi cities. Accordingly, both of the quality and safety of buildings can be ensured through imposing architectural guidelines (NTP, 2018).

2.3 Curtain Wall Systems

2.3.1 Background about Curtain Walls

Curtain walls are the external walls of buildings that do not carry loads, except their weight and wind loads (Ching, 2014; Morris, 2013b). They are supported by the structural frame of buildings instead of being loadbearing or self-supporting (Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016; Morris, 2013b). Most of the common elements of these walls are attached to the building slabs or framed columns. The attachment can be carried out through anchors or brackets (Neufert, 2019). It is known that these walls are building/cladding facades that separate or bound internal and external environments (Morris, 2013b). Since they do not bear any vertical loads, they can consist of thin, lightweight and incombustible panels regardless the building height. This provides them an advantage compared to the thick and weighty masonry loadbearing walls (Allen & Iano, 2014). There are various types of materials used in different curtain wall systems which are summarized and described in Table 2.1.

Curtain wall systems usually consist of elements that are clear and opaque. Glazing is considered to be a predominant clear element. The opaque elements of curtain wall systems include the following (McFarquhar, 2013a):

- Opaque spandrel glazing
- Metal panels and louvers

- Natural stone
- Concrete panels
- Fiber-reinforced concrete.

Table 2.1: Summary of curtain wall materials

Material	Description
Glazing	Glass provides vision to the external environment. Daylight is introduced to internal environment through it. The characterization of glass is usually based on the following: • Glass type: three basic groups characterizes the glass type: ○ Monolithic: it has a singular thickness ranging from 6 mm to 12 mm. ○ Insulating units: It is assembled of two glass lites that have separation of air in between. ○ Laminated lites: It is assembled of multi-layers of monolithic glass lites. A laminate membrane is used as an interlayer between lites. • Glass color: The iron content in glass is a major manufacturing parameter that controls the glass color. The reduction in the iron content results in clearer glass. The use of tints of No. 2 or No. 3 surfaces of insulated glasses lite units is another method to introduce color. • Glass size: Limitations of autoclaves and float plants have a major impact on the glass size. The thickness of the individual lite also limits the glass size. • Glass Strength: Three categories describe the glass strength: ○ Annealed glass: It has a continuous fabrication flow. Usually it is cut into large sheets. Accordingly, these sheets are cut into smaller lites according to the required size. ○ Heat-strengthened glass: A quick cooling process is used so that a compression layer is developed on external surfaces resulting in increased glass strength. ○ Fully tempered glass: It requires a quick temperature cooling process that is controlled so that a significant increase in the strength is achieved in compression layers of glass lites.
Metal panels	The metal panels are grouped into the following two types: • Monolithic panels: Glazing these panels into a frame of curtain wall can be similar to glass. • Composite panels: The installation of these panels can be achieved based on backup track systems. These panels consist of two external metal plates having small thickness and also internal insulation layer. Accordingly, the heat gain and heat loss from internal environments are reduced.
Precast concrete panels	The use of precast concrete panels includes covering columns and horizontal spandrels. A heavy and accurate design of connections is considered to connect the panels to the building structure.

Table 2.1: Summary of curtain wall materials (cont.)

Material	Description
Glass fiber-reinforced concrete panels	Glass fiber-reinforced concrete panels are light compared to the precast concrete panels. The mixture of these panels consists of thin concrete and reinforcing fiber. Anchors are required in sufficient amounts for the purpose of distributing internal loads and also for responding locally the lateral loads.
Natural stone	The incorporation of natural stone in curtain wall systems includes: • Covers for spandrel • Covers for columns • Accent perimeter bands The types of natural stone include sandstone, limestone, granite, marble, and travertine. The used methods to attach stone include: • Dowels and epoxy • Aluminum extruded anchors • Stainless steel anchors • Mechanical anchors

Source: (McFarquhar, 2013a)

2.3.2 Metal and Glass Curtain Walls

The aluminum frames containing various types of the glass as in-fill panels are typically used in the glass curtain wall systems (Allen & Iano, 2014; Kultermann & Spence, 2016). The wide use of these lightweight systems is due to their exceptional transparency and the rapid erection time. Spandrel panels, made from opaque glass, are used in these systems for the purpose of concealing different structural elements of buildings, such as columns, beams, and floors as well as other building elements that include electrical wiring, HVAC components and plumbing (Kultermann & Spence, 2016). Furthermore, these curtain walls can be applied to different building heights. They utilize stronger aluminum sections which are able to resist higher wind forces acting on high rise buildings. The methods associated with joining and attaching these curtain wall systems to the building structures can resist different movements resulted from both of thermal expansion and structural deflection as well as the aluminum contraction (Allen & Iano, 2014). Metal and glass curtain wall systems can have a special design for particular walls or they can be selected from standard catalogs of manufacturers (Kultermann & Spence, 2016). They can be categorized based on the assembly mode into the following systems.

2.3.2.1 Stick Systems

Stick curtain wall systems are the ones at which their elements are installed piece by piece on site (Allen & Iano, 2014; Kultermann & Spence, 2016; Morris, 2013b). They are considered as the first type of curtain wall systems used and they still remain commonly used nowadays (Kultermann & Spence, 2016). The installation process of various metal and glazed curtain walls is based on stick systems (Allen & Iano, 2014). The low shipping bulk is one of the main benefits associated with the use stick curtain walls. Moreover, the degree of adjustability of these systems for on-site conditions is high compared to others (Allen & Iano, 2014; Ching, 2014). The common use of the

stick curtain wall systems is generally in small and low rise buildings (Kultermann & Spence, 2016). Figure 2.3 illustrates the stick curtain wall system which consists of (1) anchors, (2) mullions, (3) horizontal rails, (4) spandrel panels, (5) horizontal rails, (6) vision glass, and (7) interior mullion trim.

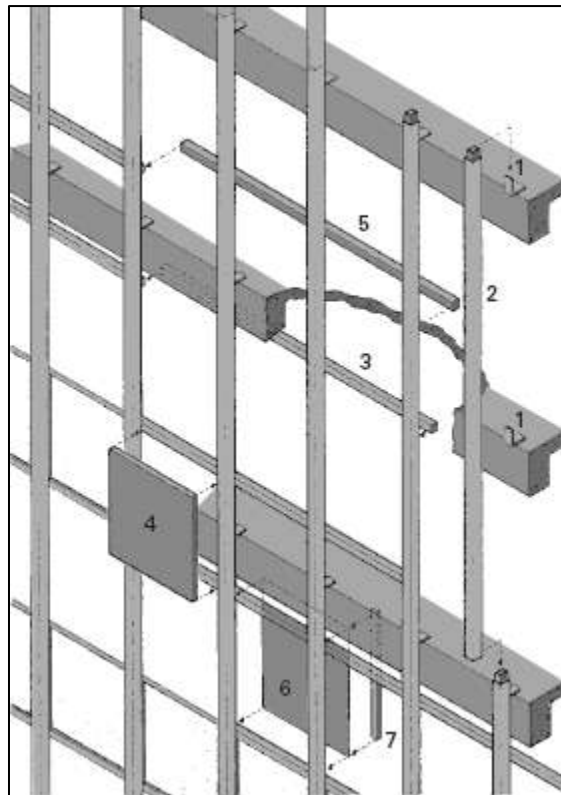


Figure 2.3: Stick System

Source: (Allen & Iano, 2014; Kultermann & Spence, 2016)

2.3.2.2 Unitized Systems

Unitized curtain wall systems consist completely of prefabricated panels (Allen & Iano, 2014; Kultermann & Spence, 2016). The fabrication and assembly of these systems is carried out in the shop (Kultermann & Spence, 2016; Morris, 2013b). Accordingly, the onsite labor work of them is less than the stick system (Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016). In

addition, the field erection time of unitized systems is generally less than the stick system (Ching, 2014; Morris, 2013b). Furthermore, unitizing improves the durability of the curtain wall system since it is carried out in a controlled environment (Morris, 2013b). The most common use of the unitized curtain wall systems is generally in large and high rise buildings (Kultermann & Spence, 2016). Figure 2.4 illustrates the unitized curtain wall system which consists of (1) anchors and (2) preassembled framed units.

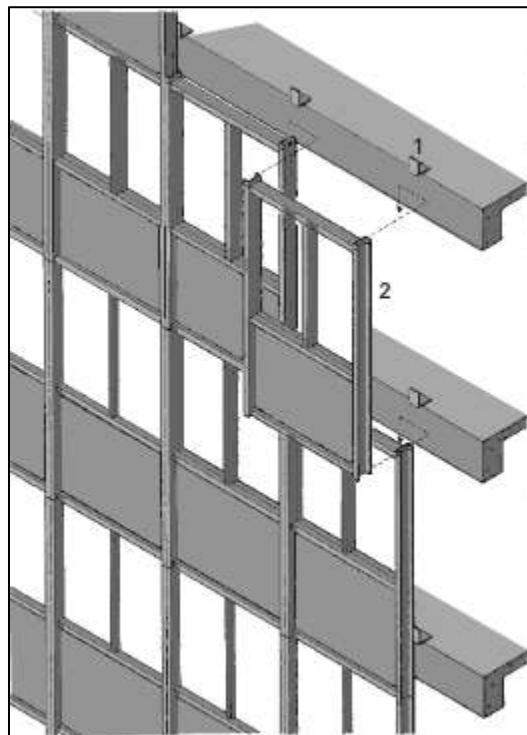


Figure 2.4: Unitized System

Source: (Allen & Iano, 2014; Kultermann & Spence, 2016)

2.3.2.3 Panel Systems

Homogenous units made of metal sheets are used to make the panels system. In fact, these curtain wall systems have the similar advantages and disadvantages to the ones in the unitized curtain walls. However, higher tooling costs of custom-made models are involved in their production.

Accordingly, their application can be advantageous only for buildings requiring higher amounts of identical units (Allen & Iano, 2014). Figure 2.5 illustrates the panel curtain wall system which consists of (1) anchors and (2) panels.

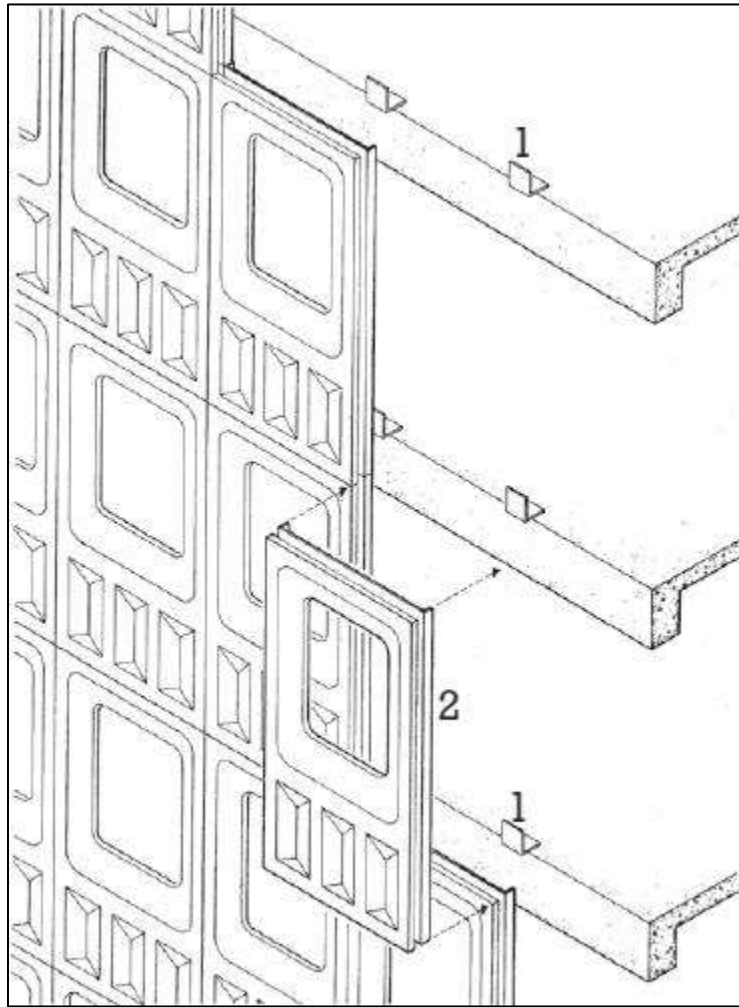


Figure 2.5: Panel System

Source: (Allen & Iano, 2014)

2.3.2.4 Unit-and-Mullion Systems

Both of the stick and unitized methods are combined in the unit-and mullion systems (Allen & Iano, 2014; Kultermann & Spence, 2016). The mullions used usually have a height of one to two story (Ching, 2014). They are installed prior to lowering panels, preassembled wall units, into the

places located behind mullions from the building interior. The height of the panels can be similar to the floor height. In addition, they can be preglazed or unglazed and also may incorporate both of vision glass as well as spandrel units (Ching, 2014; Kultermann & Spence, 2016). Figure 2.6 illustrates the unit-and-mullion curtain wall system which consists of (1) anchors, (2) mullions, (3) preassembled units lowered into places behind mullions from the story above and (4) interior mullion trim.

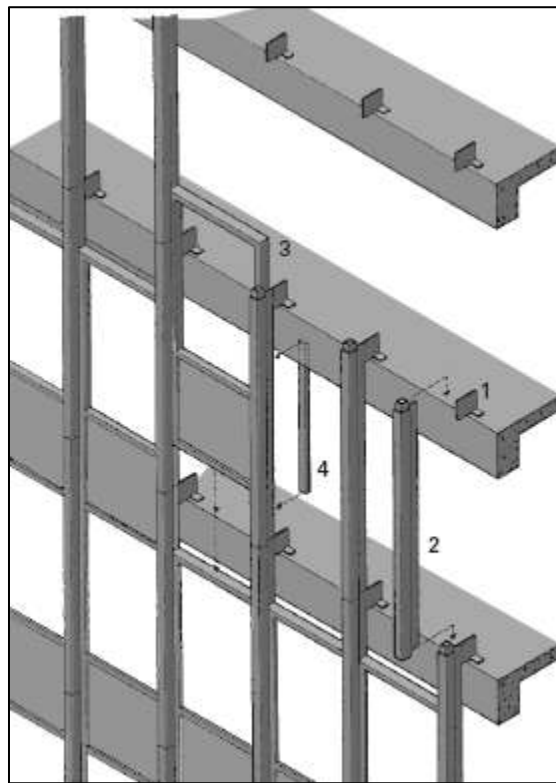


Figure 2.6: Unit-and-mullion system

Source: (Allen & Iano, 2014; Kultermann & Spence, 2016)

2.3.2.5 Column-Cover and Spandrel Systems

The structural modules of buildings are emphasized by the column-cover and spandrel systems, instead of creating their own grids of facades. Since the spacing of columns and floors varies from one project to another, custom designs of these curtain wall systems are required to be created for

each project (Allen & Iano, 2014). The column-cover and spandrel systems are considered to be relatively new and the increase of their applications may be due to their ability to offer more design alternatives (Kultermann & Spence, 2016). Both of the vision glass units and spandrel panels are included in the column-cover and spandrel systems (Ching, 2014). Hollow covers are used in these systems in order to enclose columns. The spandrel panels used are long which span between column covers (Kultermann & Spence, 2016). These panels are supported by spandrel beams located between the covered external columns (Ching, 2014). The vision glass units may be installed above spandrel panels (Kultermann & Spence, 2016). Figure 2.7 illustrates the column-cover and spandrel curtain wall system which consists of (1) column covers, (2) spandrel panels, and (3) glazing units.

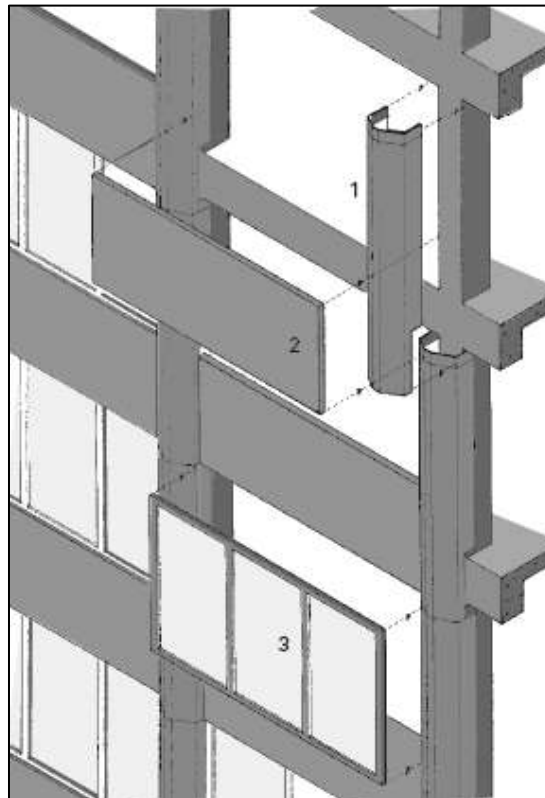


Figure 2.7: Column-cover-and -spandrel system

Source: (Allen & Iano, 2014; Kultermann & Spence, 2016)

2.3.2.6 Point-Supported Glazing Systems

The fittings and applications of the point-supported glazing systems are in fact custom and specified for particular jobs. Moreover, the architectural intent often drive the fittings associated with these systems (McFarquhar, 2013a). The point-supported glazing system generally uses mechanical anchors located at different places near the edge of the glass pane in the location of continuous edge supports. Anchoring the point supports to primary structures is typically carried out by the use of other mechanical anchors or base plates. Drilling the holes into glass panes by manufacturers facilitates supporting the panes by various point-supported elements (Kultermann & Spence, 2016). However, one of the major challenges associated with designing the point-supported glazing systems is avoiding cracks in panes under different types of loads that are expected to act on glass during its interaction with the supporting systems by mechanical anchors (Memari, 2013a). The point-supported glazing systems require minimum internal frameworks and do not utilize external pressure plates (Kultermann & Spence, 2016). Supporting systems can have different forms which may include combining glass plates, rods and cables. Different hardware and mechanisms can be used for attaching the bolt fittings, which hold the corners of panes, to the supporting system, such as the “spider” or four-pronged stainless steel fittings (Memari, 2013a). They are fixed to the support structures of buildings which can be cable or metal truss systems, steel mullions, or concrete columns (Kultermann & Spence, 2016).



Figure 2.8: Spiders fixed to building frames are used in structural standoff systems

Source: (Kultermann & Spence, 2016)

2.3.3 Metal Curtain Walls

Cladding panels of various types can be formed through using metals. Glazing the metal panels can be carried out onto curtain walls and other aluminum framings. Furthermore, the utilization of metal panels can be as an independent cladding system (Allen & Iano, 2014). The connection of metal panels can be directly carried out to the building structural frame. In addition, prefabricated metal panels can be utilized to build curtain walls and they usually have the capability to meet the requirements of strength, durability, aesthetics and insulation (Kultermann & Spence, 2016). Metal panels can be either monolithic or composite. The process of glazing monolithic metal panels is carried out through securing them into the curtain wall framing system which is similar to glass (McFarquhar, 2013a). A composite panel usually consists of a laminate of two external metal

plates having small thicknesses with an internal insulation layer (Allen & Iano, 2014; McFarquhar, 2013a). The reduction in both of the heat loss from internal spaces as well as heat gain from building exterior are provided by using the composite panels. The installation process of these panels can be individually carried out on backup track systems. There are some design features included in the metal panels can result in an increase in the plate stiffness. They can be in the form of embossed or ribbed profiles of panels (McFarquhar, 2013a).



Figure 2.9: Prefabricated metal panels

Source: (Kultermann & Spence, 2016)

2.3.4 Precast Concrete Curtain Walls

The wall panels of precast concrete are poured and steam-cured in plants away from the construction site. They are transported to the site and lifted to their positions with cranes. The

fabrication of precast units in factory environments aids in having consistent quality of finish, strength, durability. It also eliminates the formwork requirements in the construction site (Ching, 2014). Precast concrete panels have varieties of designs, thicknesses, and surface finishes (Kultermann & Spence, 2016). Their applications as cladding units can be either as the conventional reinforced panels or pre-stressed panels (Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016). The panels can solid, hollow or insulated sandwich construction having flat, ribbed, or another configuration of surfaces. The height of flat panels can go to up to two floors whereas ribbed panels can go to up to four stories. The typical thickness of solid panels varies from 4 to 10 inches. The thickness of hollow-core and sandwich panels ranges between 5 ½ to 12 inches (Kultermann & Spence, 2016).

2.3.4.1 Precast Concrete Cladding Panels

A close attention to various matters in precast concrete cladding panels, conventional reinforced or pre-stressed panels, is essentially required which include thermal insulation, mold design, surface finish, attachments to structural frames, and also the strength as well as rigidity in structural frames in order to support the panel weight (Allen & Iano, 2014). Panels can be connected to different types of structural framing systems, namely cast-in-place concrete, precast concrete or steel frames. The installation of panels can be carried out through bolting anchors cast into a panel to the receiving anchors located in the building structural frame inches (Kultermann & Spence, 2016).

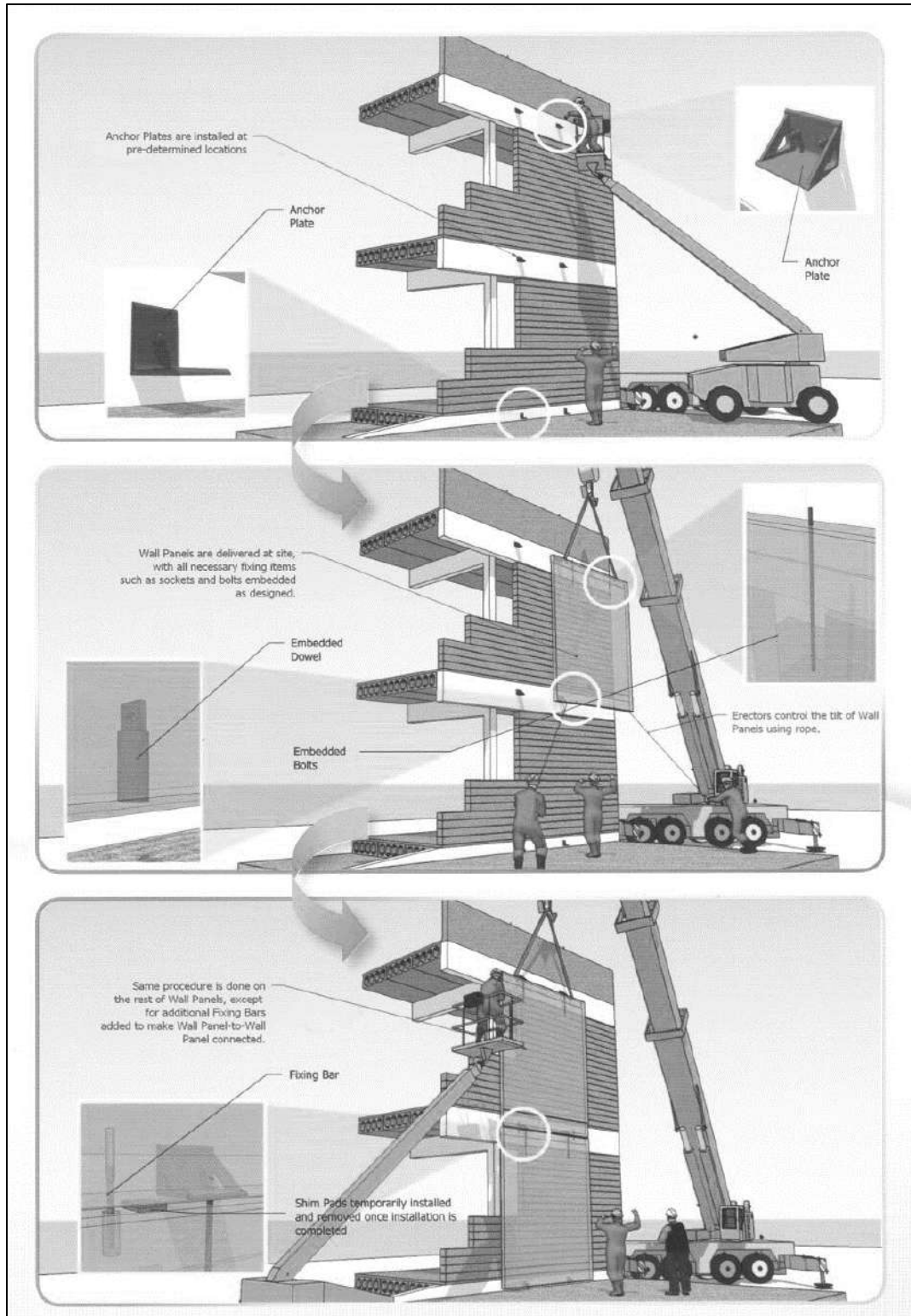


Figure 2.10: Typical architectural wall cladding installation

Source: (KPC, 2014)



Figure 2.11: Precast concrete wall panels

2.3.4.2 Glass-Fiber-Reinforced Concrete Curtain Walls

Glass fiber-reinforced concrete panels are lighter and thinner panels compared to conventionally precast reinforced concrete panels (Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016; McFarquhar, 2013a). Accordingly, this can aid in the minimizing expenditures on shipping, having easier handling with panels, and reducing the weight of attachment hardware (Allen & Iano, 2014). During the production of these panels, short glass fibers are sprayed into molds with sand slurry and Portland cement (Ching, 2014). It is possible to form various sizes and finishes from these panels (Ching, 2014; McFarquhar, 2013a). However, anchors of these panels are required in sufficient amounts for distributing internal loads and responding to lateral loads locally (McFarquhar, 2013a).

2.3.5 Masonry Curtain Walls

Masonry curtain wall systems utilize steel shelf angles to support them that are fixed to the structural systems of buildings (Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016). Laying up these walls can be carried out through the bricks at a time. This is usually similar to what is carried out in low-rise buildings (Kultermann & Spence, 2016). On the other hand, the fabrication of wall panels can be carried out on ground then a crane is used to lift them into their locations (Allen & Iano, 2014; Kultermann & Spence, 2016). In both situations, high-bond mortars can be utilized for the purpose of securing them. These mortars have appropriate bonding characteristics as well as compressive and tensile strengths (Kultermann & Spence, 2016).

2.3.5.1 Masonry Veneer Curtain Walls

The construction of masonry veneers includes a single masonry wythe anchored to the structural frames of buildings which can be used as curtain wall systems supported by concrete or steel structural systems (Ching, 2014). A cavity usually separates the single brick masonry wythe from a backup wall (Allen & Iano, 2014; Ching, 2014). Veneers are installed brick by brick with the use of conventional mortars which starts from the steel shelf angles secured to each floor in structural frames. Light gauge steel studs can be used to construct the backup walls for the stone and brick veneers. Water-resistant sheathing panels, made of cementitious or gypsum materials, are used to cover them (Allen & Iano, 2014).

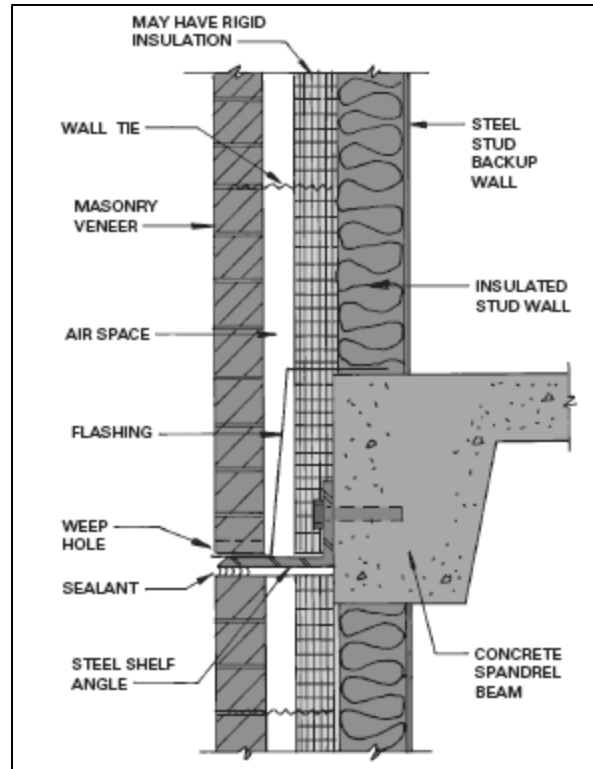


Figure 2.12: Masonry veneer curtain wall

Source: (Kultermann & Spence, 2016)

2.3.5.2 Prefabricated Brick Panel Curtain Walls

The panels are constructed at ground level then hoisted to their locations by the use of cranes (Allen & Iano, 2014; Kultermann & Spence, 2016). The panels of this curtain wall are self-rigid and do not require structural backup. In addition, their fastening process is much similar to the one in precast concrete panels. Their overall fabrication and installation processes includes the following sequential stages (Allen & Iano, 2014):

- Panels are constructed by masons in the factory through the use of conventional mortars, bricks and reinforcing bars. Bars in the vertical direction are placed inside the hollow-cores of bricks. The horizontal reinforcements can be grouted into bricks with channel shapes or laid into the joints of mortars.

- Panels are stored in order to be shipped to the construction site
- Cranes are used at the construction site to lift panels into their positions
- A single one panels can be used to construct building corners

One of the methods used to construct the prefabricated panels is through the placement of bricks inside liners of plastic gasket form. Accordingly, bricks are spaced and held in their locations. After that reinforcing bars are laid over bricks and then panels of concrete are casted over the assemblies. Liners are removed after the cure of concrete and then the panels are lifted into their positions (Kultermann & Spence, 2016).



Figure 2.13: Construction of prefabricated brick panels by masons

Source: (Allen & Iano, 2014)

2.3.6 Stone Curtain Walls

The use of stones as facings or veneers is one of the main advantages that can aid in reducing the building weight and maintaining the beauty of the appearance (Kultermann & Spence, 2016). Limestone, granite, and marble are examples of the most common types of stones that are used at the present time (Kultermann & Spence, 2016; McFarquhar, 2013a). However, the interior use of

marble can be more appropriate due to its response to the external weathering conditions. Traditional types of stones, such as limestone and granite, can be used in curtain walls as handset stone or stone trusses. Handset stones consist of panels that are individually installed supported whereas stone trusses are the panels that are individually supported on steel trusses (McFarquhar, 2013a). The production of panels requires firstly the cut of rock blocks in quarries then transporting them to mills where they are cut into panels of different thicknesses. The panel thickness depends on both of the panel size and stone type. Securing the panels to structural frames can be carried out directly piece by piece at the construction site or through fabricating them offsite and installing them as whole panels (Kultermann & Spence, 2016). It is recommended that professional architects or engineers design and review the connections of stone panel components (McFarquhar, 2013a).

2.3.6.1 Stone Panels Mounted on Steel Sub-frames

Steel framings are utilized in various curtain wall systems. Their implementation can be carried out through individual elements (McFarquhar, 2013a). The metal sub-frames mounted to structural frames of buildings, concrete or steel, are an example of mechanical systems of the conventional piece-by-piece stone curtain walls (Kultermann & Spence, 2016). The stone panels mounted on steel sub-frame are known as grid-system-supported stone claddings (Allen & Iano, 2014). The design of these systems aims at transmitting both of the gravity and wind loads from stone panels to the building structural frame. The sub-frame includes vertical elements of steel struts supporting aluminum horizontal elements (Allen & Iano, 2014; Ching, 2014). The steel struts are installed first and they should be galvanized in order to avoid straining and corrosion problems. Gypsum sheathing panels and steel studs are used to make nonstructural backup walls that have the ability

to the support finish layer of the interior walls as well as to provide air barriers (Allen & Iano, 2014).

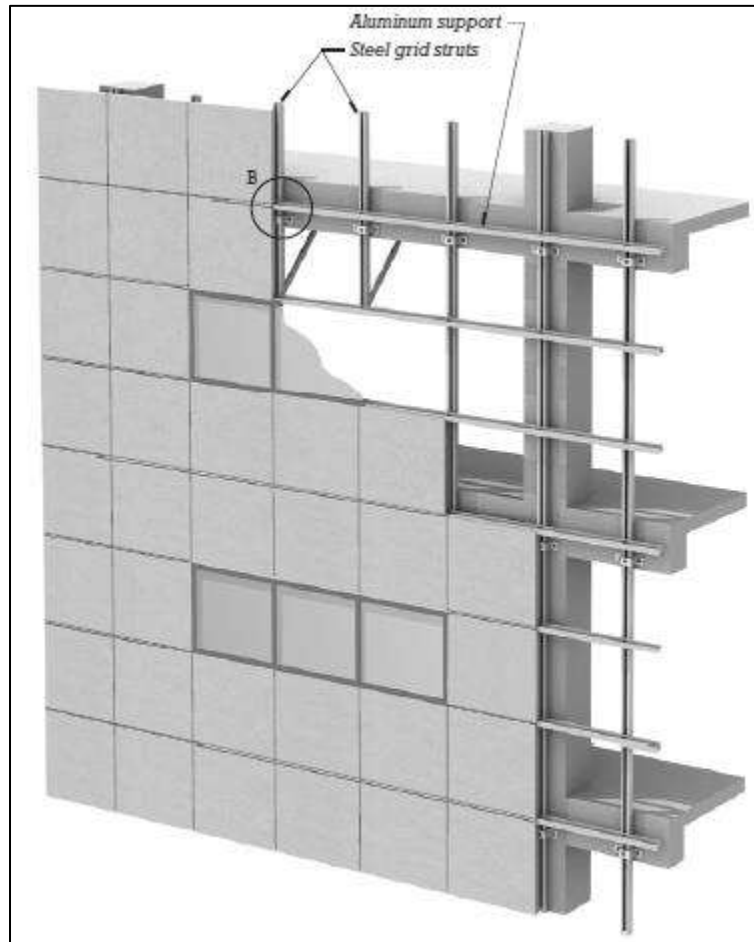


Figure 2.14: Stone panels mounted on steel sub-frames

Source: (Allen & Iano, 2014)

2.3.6.2 Monolithic Stone Cladding Panels

This stone curtain wall system requires a direct attachment of the monolithic stone panels to the building structural frame (Allen & Iano, 2014; Ching, 2014). Strap anchors, steel angles, mortar, and dowels can be used to install the panels (Kultermann & Spence, 2016). In general, the stabilization of each panel is carried out through the use of two steel angle struts bolted to the panel

with expansion anchors in holes that were already drilled. Both of backer rod and sealant are used to close the joints. Nonstructural backup wall are required in this wall system (Allen & Iano, 2014).

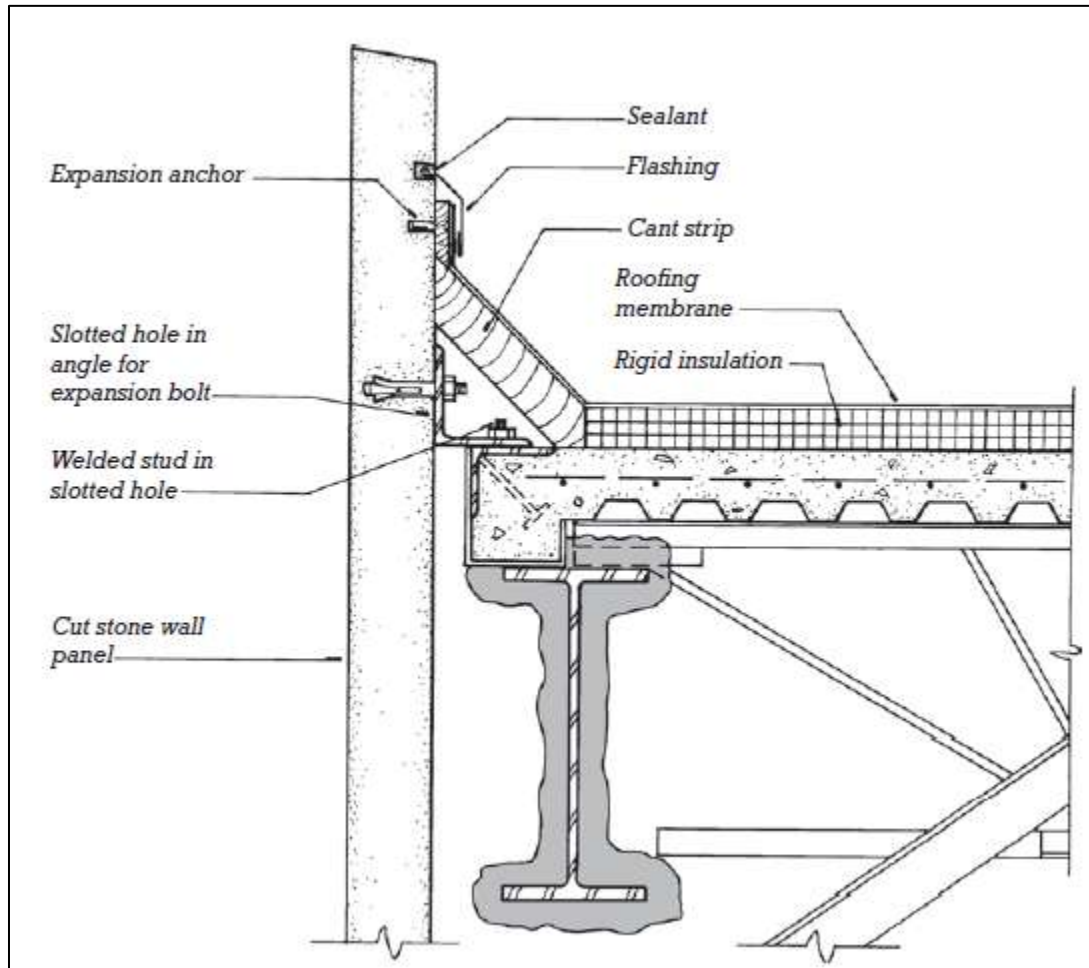


Figure 2.15: Monolithic stone cladding panel

Source: (Allen & Iano, 2014)

2.3.6.3 Stone Cladding on Steel Trusses

The fabrication of steel trusses is generally carried out by combining structural tees and angles together through either of bolting or welding which aims at forming triangulated frameworks. In addition, steel gusset plates are usually required in the connections of truss members. Structural tubing and wide-flange shapes can be used for heavy steel trusses (Ching, 2014). The assembly of

trusses is one of the implantation methods of steel framings utilized in curtain wall systems. Steel tubes and/or channels can be combined for the purpose of supporting individual stone panels (McFarquhar, 2013a). The truss-supported stone claddings are assembled through combining stone sheets into large prefabricated panels through installing them on the trusses. Both of the stone dead load and wind loads are carried by trusses to connection brackets which then transfer all loads to the building structural frame. The installation is finished by both of nonstructural backup walls and sealant joints (Allen & Iano, 2014).

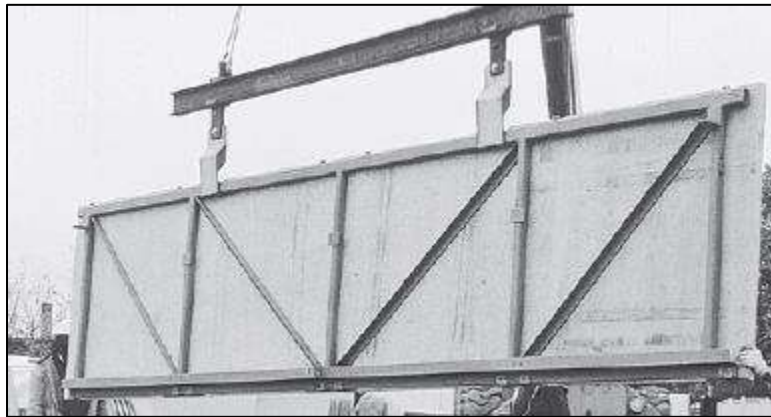


Figure 2.16: Stone cladding on steel trusses

Source: (Allen & Iano, 2014)

2.3.6.4 Posttensioned Limestone Spandrel Panels

Limestone is one of the sedimentary rocks consisting mainly of dolomite and calcite. It has three main types, namely oolitic, dolomitic, and crystalline limestone. Oolitic limestone is formed from shells having the same structure and composition. Dolomitic limestone has a main composition of magnesium carbonate and its compressive strength is higher than the oolitic. The composition of crystalline limestone is mainly from carbonate crystals. The strength of this limestone is high in both of compression and tension (Kultermann & Spence, 2016). The thickness of limestone panels varies from a minimum value of 5 cm to larger thicknesses such as a building column

(McFarquhar, 2013a). Posttensioned limestone spandrel panels consist of limestone blocks that are thick. The blocks can be joined to long spandrel panels through adhesives and posttensioned through steel tendons in order to have self-supporting assemblies between building columns (Allen & Iano, 2014).

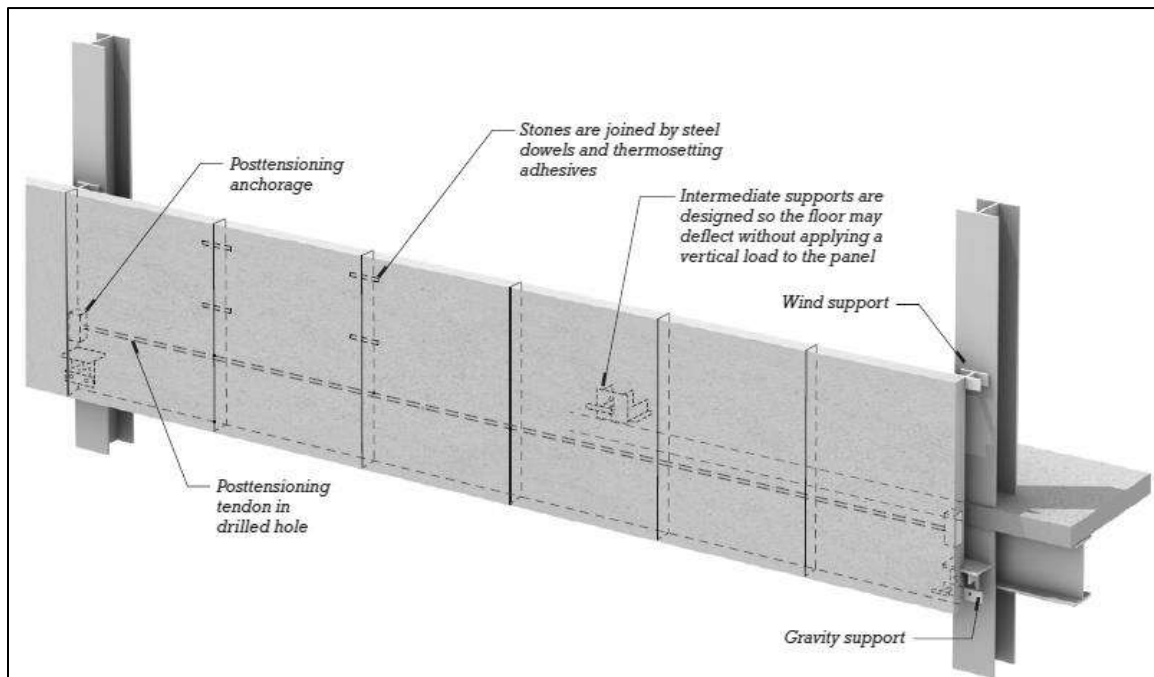


Figure 2.17: Posttensioned limestone spandrel panels

Source: (Allen & Iano, 2014)

2.4 Criteria Influencing the Selection Process of Curtain Wall Systems

According to the Project Management Institute (PMI), the criteria are defined as the “standards, rules, or tests on which a judgment or decision can be based or by which a product, service, result, or process can be evaluated” (PMI, 2017). This section aims to presents the identification of different criteria having the potential to influence the selection process of curtain wall systems. According to the performed review of literature, a total of 23 criteria was identified and categorized

into three main groups, namely: technical criteria, economic criteria, and socio-environmental criteria. This categorization was based on common interference. Table 2.2 presents the identified criteria and their references. The identification of these criteria is essential for the development of the curtain wall systems selection model that is based on multi-criteria decision-making techniques.

2.4.1 Technical Criteria

It is essential that decision-makers identify and try to achieve the required performance of the products. The performance of a product is defined as “the efficiency with which a product achieves its intended purpose” (Foster, 2017). This category includes criteria influencing the selection process of curtain wall systems which are associated with technical performances of curtain wall systems. Nine criteria were identified under this category according to the literature review, namely: structural serviceability, material weight, fire resistance, thermal performance, acoustical performance, water tightness, air tightness, compatibility, and code acceptability.

2.4.1.1 Structural Serviceability

The structural compatibility, integration, and also safety is one of the major factors associated with performance requirements that should be considered for selecting, assembling, and integrating various building systems (Ching, 2014). Generally building materials should have the following (Rosen & Bennett, 1979):

- The ability to resist wind, earthquake and other natural forces.
- They should be structurally adequate
- They should have appropriate physical properties, such as compressive and tensile strengths and also the behavior against impacts.

Therefore, it is important that curtain wall systems must be designed properly in order to avoid the serviceability failure at which the structural behavior under the service loads prevents the appropriate functioning of structures (Narayanan & Beeby, 2001). The wind load resistance by curtain wall systems is influenced by the shape and the attachment method to the building structure (Kassem & Mitchell, 2015). It is one of the engineering parameters characterizing the products of curtain wall systems (Kassem, Dawood, & Mitchell, 2012). Curtain wall systems are usually the first components of buildings exposed to wind loads. The successful design of these walls can be achieved through modeling three dimensional objects and forecasting the wind load distribution and its resistance in structures (Clift & Bonnheim, 2013). Wall systems should be able to overcome high wind speeds specially when the number of storey of the building become higher (Chew, Tan, & Kang, 2004).

The accommodation of curtain wall systems with the movement of buildings' structure is required. The dimensions and shapes of wall sections control the capacity of the accommodation of building movement (Kassem & Mitchell, 2015). In order to have safe and serviceable design of curtain wall systems under the loads of earthquakes, it is important to involve the design professional of curtain walls with structural engineering training in the early stage of the conceptual design (Memari, 2013b).

2.4.1.2 Material Weight

The weight of a building material is considered as a measure of performance. It is important that structural systems are capable to withstand the weight of curtain wall systems (Moussavi Nadoushani, Akbarnezhad, Ferre Jornet, & Xiao, 2017). The glass weight is one of the engineering parameters characterizing the products of curtain wall systems (Kassem et al., 2012).

2.4.1.3 Fire Resistance

The fire resistance, prevention, and also safety is one of the major factors associated with performance requirements that should be considered for selecting, assembling, and integrating various building systems (Ching, 2014). Fire resistance is defined as “that property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gases or flames under conditions of use” (International Code Council, 2018). Building materials should resist the effect of fire which may include smoke, the propagation of flames, toxic gases, and burn through (Rosen & Bennett, 1979). The installed system shall be capable to impede smoke and fire from a floor to another (Al-Hammad et al., 2014). The fire rating is one of the engineering parameters characterizing the products of curtain wall systems (Kassem et al., 2012). It can be defined as “The period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both” (International Code Council, 2018).

2.4.1.4 Thermal Performance

The control of heat is one of the major factors associated with performance requirements that should be considered for selecting, assembling, and integrating various building systems (Ching, 2014). The energy efficiency of buildings is influenced by the thermal performance of curtain walls (Kassem & Mitchell, 2015). The details of frame and perimeter as well in-fill panel of the glazing control the thermal performance of the wall (Song, Park, Chung, Choi, & Park, 2013). The excessive heat gain in hot weather climates results in an increase in the cost of cooling energy for maintaining desirable interior temperatures. The excessive heat loss in cold weather climates also results in an increase in the cost of heating energy. Accordingly, the design objectives of curtain wall systems that are considered for the control of heat flow can be divided into the following (Morris, 2013c):

- Control of heat loss from the internal environment in heating dominant climates
- Control of heat gain from the external environment in cooling dominant climates
- Control of air leakage.

2.4.1.5 Acoustical Performance

Noises can impact the environment negatively and also damage the psychological health of humans (Zhang, Pan, & Kumaraswamy, 2014). The acoustical privacy, isolating sounds, and also reducing noises are major factors associated with performance requirements that should be considered for selecting, assembling, and integrating various building systems (Ching, 2014). (Singhaputtangkul, Low, Teo, & Hwang, 2014) defined the “acoustic protection performance” as the “capability of the building envelope to protect against acoustic impacts during the occupation phase of a building”. Accordingly, the design and construction of a curtain wall system shall insulate the interior of a building from external noises. The infill material of a curtain wall system is a major factor that determines the acoustic performance (Kassem & Mitchell, 2015).

2.4.1.6 Water Tightness

The water tightness is one of the engineering parameters characterizing the products of curtain wall systems (Kassem et al., 2012). The design of waterproofing in curtain wall systems is extremely important in order to maintain the safety, comfort, and thermal performance of buildings and their occupants. Different features must be incorporated in curtain wall systems which include double/triple glazing for vision areas, thermal breaks in frames, and insulated spandrel pan areas (Brown, 2013). An internal drainage of water is usually considered during the design of curtain wall systems in order to allow draining out penetrated water through internal weephole. Weather resistant paints and other wall finishes can improve the resistance of the wall system (Chew, De

Silva, & Tan, 2004). Furthermore, the details of was systems including joints and architectural features can have an impact on the water infiltration (Chew, Tan, et al., 2004).

2.4.1.7 Air Tightness

Air tightness is one of the engineering parameters characterizing the products of curtain wall systems (Kassem et al., 2012). Curtain wall systems having adequate air tightness are required for preventing occupiers discomfort resulted from draughts or noises. Air leakage can lead to excessive requirements of energy and heat loss during hot and cold withers, respectively (Kassem & Mitchell, 2015). The tightness of curtain wall systems with respect to the flow of air is indicated by air infiltration. It is important especially when a large number of units are required in the installation process (McFarquhar, 2013b). Air leakage can be driven in the presence of small openings in the wall system. This can be carried out by pressure differentials across curtain walls. The creation of pressure differentials is formed by the external wind pressure, stack effect, and mechanical system. The energy loss is prevented in tight curtain walls due to the air infiltration. The creation of air tight curtain walls can be achieved by sealing joints between the framing members and adjacent materials (Morris, 2013c).

2.4.1.8 Compatibility

It is the ability of construction materials to resist reactions with other adjacent materials. The reactions include chemical interactions, galvanic actions, coating ability, or others (Rosen & Bennett, 1979). It is important that the compatibility of the interface of the curtain wall system is considered in the selection process of materials. Considering the compatibility of sealant with substrates and other types of sealant is important for preventing premature deterioration which may results in losing the water tightness of building facades (Chew, De Silva, et al., 2004; Chew,

Tan, et al., 2004). Testing the compatibility of sealant becomes a challenge due to the widely available metal finishes and glass coatings. However, the development of proprietary silicone products was found to have a successful performance (Clift & Bonnheim, 2013).

2.4.1.9 Code Acceptability

The adoption and enforcement of building codes by local the local government agencies is carried out for the purpose of regulating design, construction, alteration, and also repair of the buildings so that the public safety, health, and welfare is protected. The requirements established by building codes are generally based on (1) minimum standards for construction methods and materials, (2) occupancy and construction types of buildings, and (3) structural and fire safety specification (Ching, 2014). The building code acceptability includes reviewing codes and claims of manufactures as to the compliance of codes (Rosen & Bennett, 1979). The guidance and recommendations associated with curtain walls are provided by different organizations such as American Society of Testing Materials (ASTM), American Architectural Manufacturers Association (AAMA), Aluminum Association (AA), Glass Association of North America (GANA), and International Code Council (ICC) (McFarquhar, 2013b). Recently, the engineering and consultancy offices in the Eastern Province have been obliged to implement the requirements of the Saudi Building Code (SBC) in the design, preparation of plans and supervision of the targeted projects in the initial phase. Furthermore, supervising offices are obliged to submit certificates and reports that all of the materials as well as components utilized in a certain project comply with the SBC when applying for a building permit (Al-Mulla, 2018). SBC is involved at different aspects of curtain wall systems, such as their fire resistance as well as their assemblies (Saudi Building Code National Committee, 2018).

2.4.2 Economic Criteria

This category includes criteria influencing the selection process of curtain wall systems which are associated with economic aspects of projects. Six criteria were identified under this category according to the literature review, namely: erection time, buildability, life cycle costs, durability, maintainability, and locally available materials.

2.4.2.1 Erection Time

The erection time required is one of the major factors associated with construction practices that should be considered for selecting, assembling, and integrating various building systems (Ching, 2014). Unitized systems have a great influence to reduce the time required for closing in buildings because most the production is carried out in shops. A placement of preassembled and preglazed frames is simply involved in the installation process (Ching, 2014; Morris, 2013b).

2.4.2.2 Buildability

Buildability is defined as “the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building” (CIRIA, 1983). Its concept is considered as an architectural design approach which is based on designers’ awareness for building construction methods. Furthermore, the construction process is taken into consideration to a high degree in building construction (Hyde, 1995). The buildability of curtain wall systems can be influenced by safety, ease, and access methods (Kassem & Mitchell, 2015). According to (Singhaputtangkul et al., 2014), the achievement of the buildability of building envelopes is influenced by the following six criteria:

- Health and safety of labors: It is related to the risks of lethal and nonlethal occupational injuries that are resulted from the construction activities for building envelopes.

- **Simplicity of design details:** It is related to the standardization ability of design details for the materials and designs of building envelopes which influences the time required for the design as well as the production and review of drawings.
- **Disturbance of community:** It is related to the ability of a building envelope to avoid disturbing the community while it is constructed. This can be related to reducing the dust, toxic gases, particulate matter, the exhaust of fuels, the rise in vehicle traffic, and also the noises generated from the construction activities of a building envelope.
- **Ease in construction in accordance to time:** It is related to selecting labor-saving tools or technologies for construction, labor-efficient materials, and designs having preassembled elements in accordance with both of the availability and skill levels of labors, and suitable local practices.
- **Handling of materials:** It is related to the handling methods, both on-site and off-site, and the appropriate ways for storing the materials of a building envelope with respect to the weather protection requirements and security prior to and during the construction phase.
- **Deliveries of materials from suppliers:** It is related to the availability, quality of materials within a building envelope, traveling distance, and lead times.

2.4.2.3 Life Cycle Costs

The economics considered for any project generally include the installation cost, maintenance cost and also budgetary limitations (Rosen & Bennett, 1979). Life cycle costing can be defined as “an economic assessment of an item, area, system, or facility, considering all the significant costs of ownership over its economic life, expressed in terms of equivalent dollars” (Dell’Isola & Kirk, 1981). Accordingly, it can help in reducing overall costs of projects through the selection of components and designs minimizing the expenses of clients overall the life of projects instead of

only the time of construction (Pratt, 2011). The life cycle costs that can be considered for selecting, assembling, and integrating various building systems are (1) initial cost, including costs of materials, transportation, equipment, and labors, (2) maintenance and operating costs, (3) the consumption of energy, (4) the period of useful life, (5) costs of demolition and replacement, and also (6) the interest rate associated with the invested money (Ching, 2014). The rate and extent of building façade deterioration is affected by location of the building. Different levels of maintenance are required, and also different life cycle costs are incurred due to differences in environments, ages and heights. Quality maintenance is important due its direct effect on future maintenance costs, achievement of predicted serviceability and durability of the building façade (Chew, Tan, et al., 2004).

2.4.2.4 Durability

The durability of a product can be defined as “the degree to which a product tolerates stress or trauma without failing” (Foster, 2017). The durability can also be defined as “service life of accessories, materials, joints, and gaps in consideration of functionality, tendency to form defects, and aesthetics” (Singhaputtangkul et al., 2014). The component durability can be considered for the analysis of curtain wall systems durability. Curtain wall systems can be comprised of different components. These components can be made from varieties of materials. The behavior of the components has a major effect on the component durability. The system durability should be considered by designers. The durability of curtain wall systems depends on selecting proper materials for components having the ability to resist the effects of harsh weathering conditions (Chew, De Silva, et al., 2004).

2.4.2.5 Maintainability

The maintainability of a building material is its ease to be cleaned, repaired, recoated and others (Rosen & Bennett, 1979). It can be defined as “achieving the optimum performance throughout the building life span within a minimum life cycle cost” (Chew, De Silva, et al., 2004). (Singhaputtangkul et al., 2014) defined the “long-term burdens” as the “ease in maintenance and long-term expenses pertaining to cleaning, fixing, and replacement expenses during the occupation phase”. Curtain wall systems are required to be maintained during the operation phase of buildings. The type of a curtain wall system and the intended design life are considered to be factors controlling the degree of maintenance and inspection (Kassem & Mitchell, 2015).

2.4.2.6 Locally Available Materials

It is important that building materials are locally available in order minimize cost and time. Importing building materials that are not locally available may require long transport distances resulting in considerable high transportation costs compared to locally supplied building materials (Moussavi Nadoushani et al., 2017). In addition, the use of locally produced products can help in reducing energy consumption from the transportation (Kultermann & Spence, 2016). Furthermore, it is important that designers are aware of the available curtain wall systems instead of sticking to wall systems they know. However, they should be aware of all elements of these curtain wall systems in order to avoid the case at which suppliers might be asked to provide elements of curtain walls with a special size that cannot be accommodated (Kassem et al., 2012).

2.4.3 Socio-Environmental Criteria

This category includes criteria influencing the selection process of curtain wall systems which are associated with social and environmental aspects. Eight criteria were identified under this category

according to the literature review, namely: aesthetics, visual performance, embodied energy, resource consumption, waste generation, reusability, recyclability, and toxicity and indoor environment.

2.4.3.1 Aesthetics

The aesthetic qualities should be considered for selecting, assembling, and integrating various building systems. This includes desired relationships of buildings to their sites, neighborhood, and adjacent properties. Moreover, aesthetics in buildings include preferred qualities of colors, massing, form, details, texture, and pattern (Ching, 2014). (Singhaputtangkul et al., 2014) defined the “appearance demands” as the “combination of style, image and aesthetics considerations of the building envelope as a whole”. The aesthetics of products can be defined as “subjective sensory characteristics such as taste, feel, sound, look, and smell” (Foster, 2017). According to this subjectivity, viewing the beauty of a particular curtain wall system may have a considerable variation from one person to another (Moussavi Nadoushani et al., 2017). Special types of natural stone can provide aesthetic options for designers due to their intricate veining. The aesthetics of curtain walls are influenced by the type of glazing materials used in walls. The aesthetics of façades can influence the selection of framing element, aluminum or steel frames, of curtain wall systems (McFarquhar, 2013a). Since buildings are usually built within existing societies and can have a high impact on both of their users and surrounding communities, the aesthetics of buildings can be considered as a social impact indicator (Moussavi Nadoushani et al., 2017).

2.4.3.2 Visual Performance

The visual performance of a building envelope can be defined as its optimization ability for the visual comfort of building occupants (Singhaputtangkul et al., 2014). Light is provided for the

internal environment of buildings through solar radiations. There are psychological benefits associated with this daylight. Furthermore, it can help in reducing the energy consumption in artificial lighting. The determination of the quantity and quality of the daylight in the interior spaces is controlled by the sizes and orientations of windows, transmittance of glass, reflectance of outdoor surfaces and also room surfaces, and the obstructive nearby trees (Ching, 2014). The transmittance and reflectance of light are considered as the most obvious properties of glass that provide the architectural appeal of glazed curtain walls. The transmission of light can help in the allowance of natural lighting to the internal environment of buildings. Furthermore, views from internal environments of buildings are allowed through this property which provides closer connections to the natural external environment. Glazed materials reflect their surroundings in daylight. These unique properties to glass resulted in an increase in the popularity of using it in multistory buildings (Morris, 2013a). Double-skin facades are designed for the purpose of conserving and reducing the energy required for lighting buildings. They have the ability to control solar radiations and daylights (Ching, 2014). The transmittance of the desirable visible light is reduced by tinted glass through blocking large proportions of visible wavelengths. Accordingly, this type of glass is not appropriate for reducing solar gains (Morris, 2013c).

2.4.3.3 Embodied Energy

Embodied energy is one the considerations added by green buildings for choosing between wall systems (Ching & Shapiro, 2014). It can be defined as “the energy consumed by all processes associated with the production and use of a material or assembly, from the acquisition of natural resources to its final reuse or demolition” (Kultermann & Spence, 2016). The measurement of the embodied energy is expressed as the quantity of nonrenewable energy (megajoules or gigajoules) per a unit of the building material or component per unit of area (square meter or foot) or weight

(kg or ton) of a material (Kultermann & Spence, 2016). The embodied energy varies between different façade materials due to the variation in energy required for producing and processing the materials. Moreover, there might be variations in the total quantity of materials used in the façade from one façade to another. The calculation of the embodied energy of a façade is conducted based on the multiplication of quantities of various materials within the façade by the corresponding embodied energy of each material (Moussavi Nadoushani et al., 2017). The life cycle analysis (LCA) is the only way for full quantification of this energy. It is considered as a detailed procedure required for the compilation and analysis of inputs and outputs associated with energy and resources and their environmental impacts generated from using materials throughout their life cycles (Kultermann & Spence, 2016). (Singhaputtangkul et al., 2014) defined the energy consumption associated with the construction of a building envelop as the “consumption of electricity of power tools and fuel of heavy equipment for building envelope installation and construction-related activities during construction”.

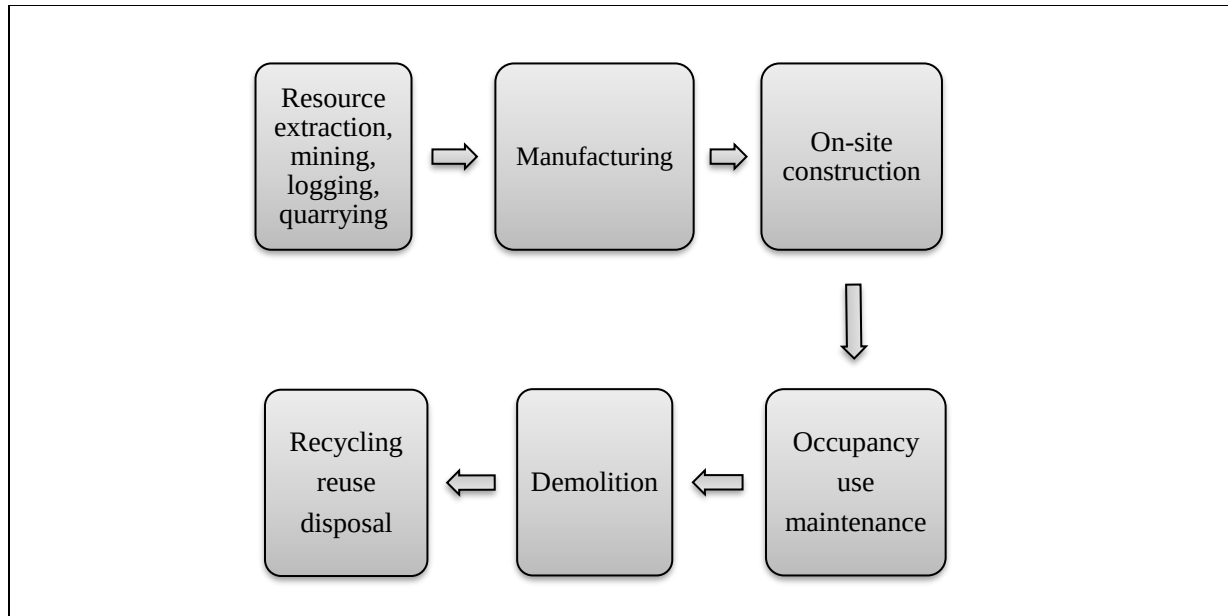


Figure 2.18: Stages considered for the determination of embodied energy in building materials

Source: (Kultermann & Spence, 2016)

2.4.3.4 Resource Consumption

The reduction in the consumption of construction resources is an imperative challenge for governments and companies in different levels of the industry which aims at developing sustainable construction (Kultermann & Spence, 2016). The resource in a project is defined by the PMI as “a team member or any physical item needed to complete the project”(PMI, 2017). The resource consumption associated with the construction of a building envelop is defined as the “consumption of construction resources including water, chemicals, formwork materials, aggregates, sealants, plasters, and joints in installation and construction of the building envelope” (Singhaputtangkul et al., 2014). The minimization in materials consumed during the manufacturing and installation of curtain wall systems is considered as an attribute of green materials.

2.4.3.5 Waste Generation

The waste generation associated with the construction of a building envelop is defined as the “generation of wastes in the forms of excessive concrete, mortar, sealants, cleaning chemical and water, aluminum or vinyl window frame, concrete blocks, bricks, bricks, and glazing materials during construction” (Singhaputtangkul et al., 2014). The construction waste can be generated from different factors related to the management and workforce aspects such as the lack of a system for managing quality and also lack of skilled labors and subcontractors (Al-Rifai & Amoudi, 2016). The reduction in the waste is considered as a major focus associated with construction waste management which aims at avoiding filling landfills. The concentration on the efficient use of materials during the design and procurement is considered as the beginning of the construction waste management process. The facilitation of efficient procurement is based on a detailed identification of material quantities resulting in less waste. Additionally, the protection construction materials onsite prior to their use is an important consideration in green buildings. It can help in preventing the damage of materials which may affect their functionality and also indoor air quality (Ching & Shapiro, 2014). The acceptance of the manpower growth by the construction practitioners can be considered as a collaborative and operations technique. It can result in gradual enhancements of the practical experiences, attitude and skills of labors required for operating well on assigned activities, and cumulatively enhances the reduction of wastes (Umar, Shafiq, Malakahmad, Nuruddin, & Khamidi, 2017). The prefabrication is one of the methods that can result in reducing construction waste (Y. Chen, Okudan, & Riley, 2010; Li, Shen, & Alshawi, 2014; C. M. Tam, Tam, Chan, & Ng, 2005; V. W. Y. Tam, Tam, Zeng, & Ng, 2007). Prefabrication is defined as the “construction that takes place in a factory or shop, rather than on the building

site” (Allen & Iano, 2014). Accordingly, the installation of unitized systems can result in less amount of waste onsite compared to stick built systems.

2.4.3.6 Reusability

Reusing durable products is one of the source reduction techniques that can be carried out through the repair or refurbishment of broken or outdated products, respectively (Davis & Masten, 2014). Considering the possibility of reusing present buildings and materials is one of the guidelines that are taken into account for achieving the sustainability in the design and construction of buildings (Kultermann & Spence, 2016). Reusing materials whenever it is possible can help in the minimization of both of the following (Ching & Shapiro, 2014):

- Embodied energy required for harvesting and processing new materials.
- The depletion of raw material sources

Reusing of products does not require reprocessing of items and therefore it is more preferable than recycling (Davis & Masten, 2014). However, the environmental impacts associated with the reuse of a building material may not be fully understood and also the industry may only depend on recycling as a main alternative for the waste management (Rios, Grau, & Chong, 2019). Therefore, designers should have a proper approach facilitating the reuse of various building materials. In fact, the design for the deconstruction is an approach that can help in achieving the reuse of the materials at the end of the service life of buildings and its principles include the reduction in the complexity of buildings, use of modular construction, selection of durable and reusable building materials, reduction in the number of fasteners when it is possible, selection of fasteners allowing an easier deconstruction, and simplification connections (Ching & Shapiro, 2014).

2.4.3.7 Recyclability

The design of a building that provide a longer service life and eventual recycling of various building elements is one of the guidelines that are taken into account for achieving the sustainability in the design and construction of buildings (Kultermann & Spence, 2016). The recyclability of materials in buildings has a considerable contribution to the sustainable construction through the reduction of negative impacts associated with the end of a building material life (Moussavi Nadoushani et al., 2017). Hence, the categorization of the recyclability is considered as a one of the environmental criteria (Akadiri, Olomolaiye, & Chinyio, 2013; Y. Chen et al., 2010). Recycled materials in any product are categorized into the following (Ching & Shapiro, 2014):

- Preconsumer recycled materials: There are different types of waste materials generated during the manufacturing process of any product. The recycled ones from the waste stream are the preconsumer recycled materials
- Postconsumer recycled materials: They are the materials that were collected from the wastes generated from the end users and then recycled into raw materials used for the manufacturing of new products.

The recycling process is categorized into the following three processes (Davis & Masten, 2014):

- Primary recycling: This process aims at using recycled products for the purpose of making similar products.
- Secondary recycling: It aims at using recycled products for the purpose of making new products having characteristics that are different from original products.
- Tertiary recycling: It aims to recover energy or chemicals from the postconsumer materials.

There are different types of materials that are recycled which include the papers, plastics, glass and different types of metals such as aluminum, steel, and copper. The recycling process of glass considered as one of the easiest recycling processes (Davis & Masten, 2014). The aggregate contained in concrete can be recycled by crushing the concrete after the removing steel reinforcement bars and other types of embedded materials (Ching & Shapiro, 2014).

2.4.3.8 Toxicity and Indoor Environment

(Singhaputtangkul et al., 2014) defined the “health, safety, and security of occupants and society” as the “selection of the building envelope materials that contain no hazardous substances, can resist fire, and can provide security to the occupants and society”. The use of non-toxic materials is one of the guidelines that are taken into account for achieving the sustainability in the design and construction of buildings (Kultermann & Spence, 2016). Materials having low toxicity are the ones containing a low content of volatile organic chemicals (VOCs) (Ching & Shapiro, 2014). There are various artificial products consisting of (VOCs) that have the tendency to off-gas from machines, furniture, and interior materials which can result in poor indoor air quality. The occurrence of the off-gassing is based on the evaporation of chemically unstable solid materials at room temperature and the slow release of a contaminant into air (Kultermann & Spence, 2016). Poor indoor air quality can result in a reduction in the performance of works carried out in offices by 6 to 9% (Wyon, 2004). The indoor air quality in buildings is defined as “the overall measure or absence of indoor airborne contaminants, such as particles, tobacco smoke, carbon dioxide, hazardous chemicals, odors, humidity, and biological contaminants” (Ching & Shapiro, 2014). It is ranked by the Environmental Protection Agency (EPA) as a one of the most critical environmental issues nowadays (Kultermann & Spence, 2016). The improvement in the air quality is one of the goals aimed to be achieved by green buildings for the purpose of improving the human

health and comfort. It can be achieved through the following four approaches (Ching & Shapiro, 2014):

- Reducing the contaminant sources: This can be carried out through the use of carpeting or paints emitting lower amount of chemicals
- Contaminant capture: This can be carried out through the interception of contaminants prior to reaching the breathing zone of people
- Filtration: This is based removal of contaminants from air
- Dilution: The dilution with outdoor (ventilation) aims at eliminating, capturing, or filtering contaminants that cannot be handled by the aforementioned approaches.

The prefabrication of a building element usually has a controlled environment at which dry materials are used and therefore this minimized moisture level can have a correlation to low risks of indoor air quality problems (Y. Chen et al., 2010). In addition, the indoor air quality can be improved by the use of double-skin façade systems (Memari, 2013a).

Table 2.2: Criteria involved in the selection process of curtain wall systems (according to the literature)

Category	No.	Criteria	References
Technical Criteria	1	Structural Serviceability	(Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Allen & Iano, 2014; Chew, Tan, et al., 2004; Ching, 2014; Chudley & Greeno, 2014; Clift & Bonnheim, 2013; Kassem et al., 2012; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; Memari, 2013b; Rosen & Bennett, 1979; Wong & Li, 2008)
	2	Material Weight	(Kassem et al., 2012; Moussavi Nadoushani et al., 2017)
	3	Fire Resistance	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Allen & Iano, 2014; Ching, 2014; Chudley & Greeno, 2014; International Code Council, 2018; Kassem et al., 2012; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017; Rosen & Bennett, 1979; Singhaputtangkul et al., 2014; Wong & Li, 2008)
	4	Thermal Performance	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Allen & Iano, 2014; Y. Chen et al., 2010; Chew, Tan, et al., 2004; Ching, 2014; Chudley & Greeno, 2014; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; Morris, 2013c; Moussavi Nadoushani et al., 2017; Singhaputtangkul et al., 2014; Ünver, Akdağ, Gedik, Öztürk, & Karabiber, 2004)
	5	Acoustical Performance	(Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Allen & Iano, 2014; Ching, 2014; Chudley & Greeno, 2014; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017; Singhaputtangkul et al., 2014; Ünver et al., 2004; Zhang et al., 2014)
	6	Water Tightness	(Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Allen & Iano, 2014; Brown, 2013; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Ching, 2014; Chudley & Greeno, 2014; Kassem et al., 2012; Kassem & Mitchell, 2015; Kultermann & Spence, 2016)
	7	Air Tightness	(Al-Hammad et al., 2014; Allen & Iano, 2014; Kassem et al., 2012; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; McFarquhar, 2013b; Morris, 2013c)
	8	Compatibility	(Al-Hammad & Hassanain, 1996; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Clift & Bonnheim, 2013; Kultermann & Spence, 2016; Rosen & Bennett, 1979; Wong & Li, 2008)
	9	Code Acceptability	(Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016; McFarquhar, 2013b; Rosen & Bennett, 1979)

Table 2.2: Criteria involved in the selection process of curtain wall systems (according to the literature) (cont.)

Category	No.	Criteria	References
Economic Criteria	10	Erection Time	(Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Y. Chen et al., 2010; Ching, 2014; Morris, 2013b)
	11	Buildability	(Akadiri et al., 2013; Allen & Iano, 2014; Y. Chen et al., 2010; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Chudley & Greeno, 2014; CIRIA, 1983; Hyde, 1995; Kassem & Mitchell, 2015; Singhaputtangkul et al., 2014)
	12	Life Cycle Costs	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; O. Alshamrani et al., 2017; Y. Chen et al., 2010; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Ching, 2014; Dell’Isola & Kirk, 1981; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017; Rosen & Bennett, 1979; Singhaputtangkul et al., 2014; Wong & Li, 2008; Zhang et al., 2014)
	13	Durability	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Y. Chen et al., 2010; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Ching, 2014; Foster, 2017; Moussavi Nadoushani et al., 2017; Singhaputtangkul et al., 2014)
	14	Maintainability	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Chew, De Silva, et al., 2004; Chew, Tan, et al., 2004; Ching, 2014; Chudley & Greeno, 2014; Kassem & Mitchell, 2015; Kultermann & Spence, 2016; Rosen & Bennett, 1979; Singhaputtangkul et al., 2014; Zhang et al., 2014)
	15	Locally Available Materials	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Ching & Shapiro, 2014; Kassem et al., 2012; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017)

Table 2.2: Criteria involved in the selection process of curtain wall systems (according to the literature) (cont.)

Category	No.	Criteria	References
Socio-Environmental Criteria	16	Aesthetics	(Akadiri et al., 2013; Al-Hammad & Hassanain, 1996; Al-Hammad et al., 2014; Y. Chen et al., 2010; Chew, Tan, et al., 2004; Ching, 2014; Ching & Shapiro, 2014; Foster, 2017; McFarquhar, 2013a; Moussavi Nadoushani et al., 2017; Singhaputtangkul et al., 2014)
	17	Visual Performance	(Al-Hammad et al., 2014; Allen & Iano, 2014; Ching, 2014; Kultermann & Spence, 2016; Morris, 2013a, 2013c; Singhaputtangkul et al., 2014; Ünver et al., 2004; Zhang et al., 2014)
	18	Embodied Energy	(Akadiri et al., 2013; Y. Chen et al., 2010; Ching & Shapiro, 2014; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017; Singhaputtangkul et al., 2014)
	19	Resource Consumption	(Y. Chen et al., 2010; Ching, 2014; Ching & Shapiro, 2014; Singhaputtangkul et al., 2014)
	20	Waste Generation	(Akadiri et al., 2013; Al-Rifai & Amoudi, 2016; Y. Chen et al., 2010; Ching & Shapiro, 2014; Li et al., 2014; Singhaputtangkul et al., 2014; C. M. Tam et al., 2005; V. W. Y. Tam et al., 2007; Umar et al., 2017)
	21	Reusability	(Akadiri et al., 2013; Y. Chen et al., 2010; Ching & Shapiro, 2014; Davis & Masten, 2014; Kultermann & Spence, 2016; Rios et al., 2019)
	22	Recyclability	(Akadiri et al., 2013; Y. Chen et al., 2010; Ching & Shapiro, 2014; Davis & Masten, 2014; Kultermann & Spence, 2016; Moussavi Nadoushani et al., 2017)
	23	Toxicity and Indoor Environment	(Akadiri et al., 2013; Y. Chen et al., 2010; Ching & Shapiro, 2014; Kultermann & Spence, 2016; Singhaputtangkul et al., 2014; Wyon, 2004)

2.5 Previous Research

Significant efforts have been carried out on different aspects of wall systems pertaining to the building industry. (O. Alshamrani et al., 2017) conducted a study on the selection of external wall materials by applying the Life-Cycle-Costing (LCC) technique during the design phase. The study was conducted on a high-rise building located in the Eastern Province of Saudi Arabia. Fourteen different external wall materials that are commercially available were employed to evaluate the LCC of the building. Both of the Autodesk REVIT (2015) and ECOTECT (2011) softwares were used for modeling the building and calculating the energy consumption of the building, respectively. Crystal Ball software was employed to use Monte Carlo simulation technique for performing uncertainty and sensitivity analyses. The study focused only on the life cycle cost as a tool for selection. Many other parameters and criteria should be considered in the selection process.

(Volf et al., 2018) conducted a research for designing a curtain wall panel system in the European Union through the application of design strategies for both of the low embodied energy and embodied carbon so that wall system (1) is appropriate for replacing obsolete walls of the constructed facilities or for creating envelopes for new facilities, (2) enables reaching a nearly zero-energy standards in facilities at which the application of the wall system is carried out, (3) consumes lower primary energy and emits lower carbon amounts while it is produced compared to the standard systems. A comparative life cycle assessment was used for analyzing the technical concept. The verification of the technical performance was conducted by testing prototypes. A detailed life cycle assessment was conducted on the final design on the pre-production. Moreover, different probabilities were suggested and assessed for the improvements of the final design. According to early stage of the life cycle assessment, it was found that the embodied environmental impact had a high potential to be reduced by using natural materials. It was proved that the standard

technical requirements were fulfilled by the developed wall system according to the experimental testing. Fabricating a panel of the developed curtain wall system had a significant lower environmental impact based on the detailed pre-production life cycle assessment study.

(Radhi, 2010) conducted a study for the analysis of performance of wall systems and cladding materials based on their impact on the CO₂ emissions so that designers are provided with reliable technical data. The exterior wall and finish systems, aluminum siding, masonry veneer, and other systems were included in the study. Using a green building modeling system was considered for the purpose of evaluating both economic and environmental performances and also the embodied energy. Using a simulation model and then constructing a simple bottom-up model were considered for the estimation of the operational energy impact. A sensitivity analysis was performed for the determination of the relative impact of each single wall system on a representative school building. The results show using some cladding materials resulted in a reduction of the CO₂ emissions while the operational energy moderately reduced, and vice versa. Other materials were found to have a positive impact on both of the environmental impact and the embodied energy and also the operational energy performance was optimized by these materials. Essential factors and parameters, such as the simplicity of design details, durability, availability of materials, and the recyclability of materials were not covered in the study.

(Rapone & Saro, 2012) conducted a study that aimed to find the configuration of a modelled and studied typical curtain wall façade for an office building. The determined configuration had selected parameters minimizing the total carbon emissions that arise from the building operations. A fully automated search was performed by using simulation-based optimization techniques, the integration of a PSO algorithm with a dynamic energy simulation engine, in order to find the optimized values of envelop features. The algorithm performance in the generation of satisfactory

results was examined. The study suggested a way for finding addition solutions that are near the optimum so that diversity is provided. The study also investigated the influence of different alternatives of exterior shading devices and also different climates.

(Al-Hammad & Hassanain, 1996) conducted a study for the purpose of evaluating and selecting exterior wall systems through the application of value engineering principles. Sixteen performance criteria were obtained from a questionnaire survey distributed over 25 designers and consultants. Fourteen different exterior wall systems were included in the study.

(Chew, Tan, et al., 2004) conducted a study for the purpose of proposing assessment framework for curtain walls and cladding facades based on conducting interviews face-to-face with a total number of 55 building managers and also surveying comprehensively the condition of commercial buildings. A total 28 parameters were identified with significance to influence the assessment score of the maintainability of facades during the service life. The attribution of the technical assessment index had relative weights of 2.5% of environment, 3.6 % of construction, 14.5% of customer satisfaction, 37.8% of design, and 41.6% of maintenance factors.

(Kassem et al., 2012) conducted a research for the purpose of empirically analyzing the selection process of curtain wall systems during the design development stage through the use of both of a retrospective case study in the United Kingdom and also a survey conducted on the industry and then presenting and testing a decision support system enabling the process of selecting curtain wall systems. A decision support system with an integration of all different available curtain wall systems from suppliers in a database was proposed. The developed system enables resolving issues related to curtain wall selection during design development stage and also identifying different commercial and technical alternatives if they were presented to a client in a real time. The

consideration of a comprehensive list of economic, social and environmental factors is one of the major aspects were not considered in such system.

(Al-Hammad et al., 2014) conducted a study for the purpose of assessing and selecting curtain wall systems used for buildings having medium to high rises located in Saudi Arabia. Different alternatives that have a common use in the Saudi building construction industry were identified. Then different performance and also fiscal and non-fiscal criteria influencing the assessment and selection of the wall systems were examined. The identified walls were subjected to different filtering processes that included feasibility ranking, comparative evaluation and weighted evaluation for the facilitation of the selection of the suitable wall system. The data collection and analysis revealed that the first choice of curtain wall systems was the precast concrete wall system. The prefabricated brick panel wall was found to be the second choices of curtain wall systems. However, there was a lack of considering socio-environmental criteria in this study which are essential for achieving the sustainable development of constructed facilities.

2.6 Summary

This chapter covered a background about the building construction sector in Saudi Arabia, curtain wall systems, criteria influencing the selection process of curtain wall systems, and previous research. The development of technologies is taken into consideration by the Saudi government for the purpose of rationalizing the consumption of water and energy and also adopting sustainability and friendly environment concepts on buildings. Curtain wall systems present major elements influencing the life cycle cost of office buildings. Various criteria were found to have an influence on the selection process of the curtain walls. Having the right designer is a key factor for the selection of suitable curtain wall system. The development of an effective multi-criteria

decision-making model that can be easily used is important in order to assist designers to select the right curtain wall systems based on the involvement of different criteria.

The integration of sustainable development concepts during the early design stages is an essential task that should be handled effectively by professionals involved in the design and selection of curtain wall systems. The literature reveals that there is a lack of considering an integrated list of technical, economic, and socio-environmental criteria used for selecting curtain wall systems used for mid- and high-rise office buildings. Therefore, the development of a generic model integrating such criteria is important for expanding the boundaries of knowledge of having a systematic approach for decision-makers.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research methodology that was designed to achieve the objectives of the study. A set of eight sequential steps pertaining to that achievement were followed in this study. Figure 3.1 summarizes the research methodology. Two steps, namely literature review and interviews with local experts, contributed for achieving the first objective. The second objective was achieved by five steps. Those steps are the design of questionnaire survey, pilot-testing of the questionnaire, data collection, data analysis, and development and implementation of the MCDM model. The last step contributed in achieving the third objective.

3.2 Achievement of the First Objective

“To identify most common alternatives of curtain wall systems utilized in office buildings and their selection criteria”

3.2.1 Literature Review

A comprehensive literature review was performed for the purpose of identifying different alternatives of curtain wall systems utilized in the building construction industry. In addition, it aims to identify various criteria influencing the selection of curtain wall systems. The literature reveals that there are different curtain wall systems utilized in the building construction that include metal and glass curtain walls, metal curtain walls, precast concrete curtain walls, masonry

curtain walls, and stone curtain walls. Furthermore, there are different technical, economic, and socio-environmental criteria that influence the selection process of curtain walls.

3.2.2 Interviews with Local Experts

The purpose of conducting interviews with local experts is to identify the most common alternatives of curtain wall systems used for office buildings in Saudi Arabia. Furthermore, the interviews aim to add or eliminate criteria influencing the selection process. The representatives of engineering and architectural design firms, involved in the design and selection of curtain wall systems for office buildings in the Eastern Province of Saudi Arabia, are considered at different stages of this study because they are the ones responsible for converting both of the conceptions and needs of owners into a specific facility having certain dimensions based on drawings and specifications including economic considerations (Rumane, 2017). Those representatives are usually engineers and architects and are also licensed professionals (Clough, Sears, Segner, & Rounds, 2015).

A set of semi-structured interviews are conducted with experts working in engineering and architectural design firms in the Eastern Province of Saudi Arabia. In those interviews, the identified lists of curtain wall systems as well as their selection criteria are shared with them (Fellows & Liu, 2015). The experts' feedback regarding the wall alternatives commonly used in office buildings located at the Eastern Province of Saudi Arabia and the selection criteria are recorded.

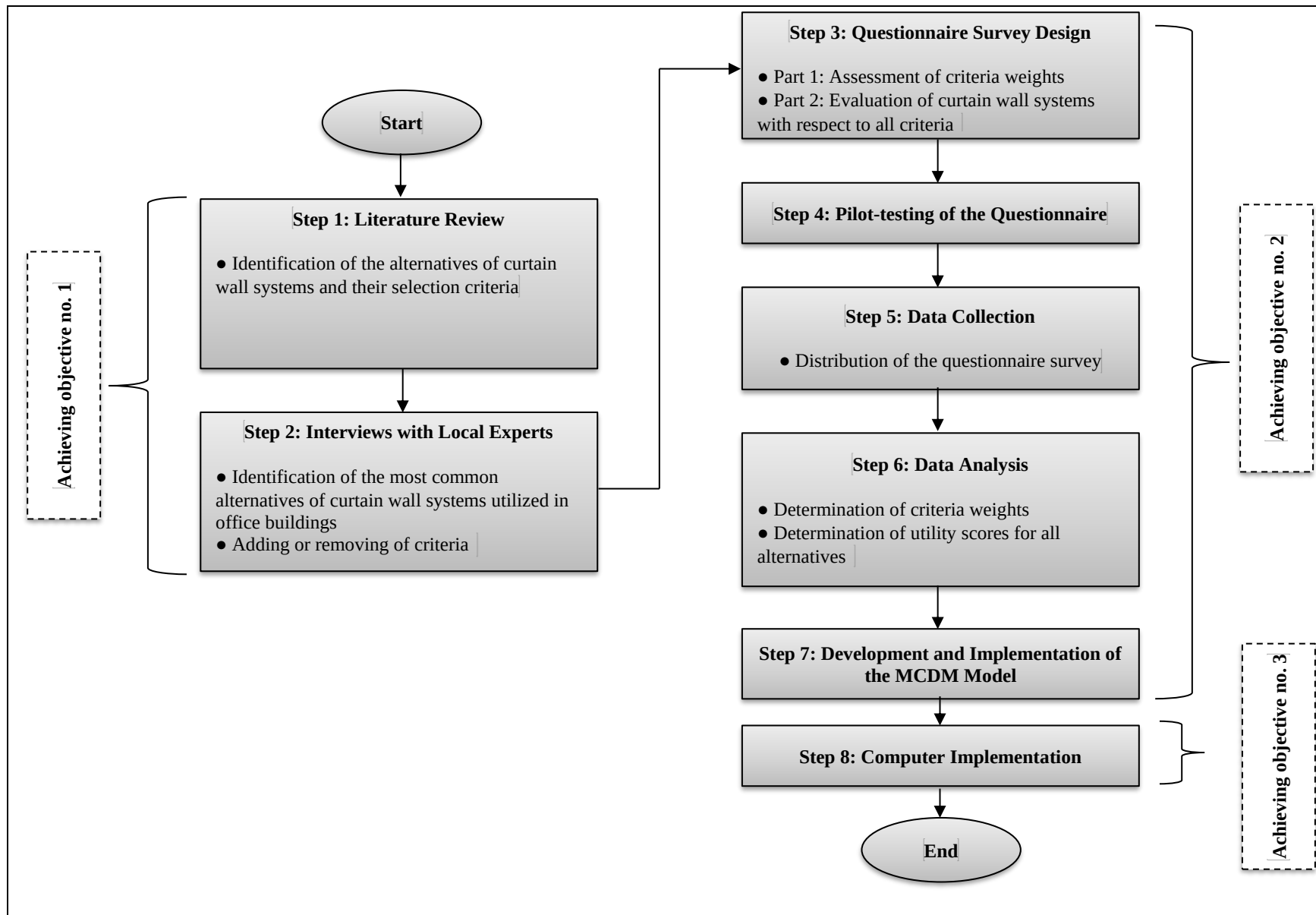


Figure 3.1: Summary of research methodology

3.3 Achievement of the Second Objective

“To develop an MCDM model for evaluating, ranking, and selecting curtain wall systems utilized in office buildings”

3.3.1 Questionnaire Design

3.3.1.1 Required Data

The main benefit of collecting data from respondents is that it can aid in the maximization of the amount as well as accuracy for the purpose of transferring the meaning from providers to researchers (Fellows & Liu, 2015). A set of curtain wall systems and their selection criteria are identified through conducting comprehensive literature review and interviews with local experts in the Eastern Province of Saudi Arabia. The performance of curtain wall systems with respect to a certain criterion varies from one alternative to another. Moreover, the prioritization of criteria usually is not equal. Some criteria have higher priority than others. In order to handle such situation, MCDM techniques are considered to be used in the destined questionnaire survey which contribute to the development of a model that facilitates the process of evaluating, ranking, and selecting curtain wall systems utilized in office buildings. Accordingly, the required data for this study is as the following:

1. A consistent prioritization of all quantitative and qualitative criteria influencing the selection process of curtain wall systems used in office buildings located in the eastern province of Saudi Arabia
2. An evaluation of the performance of all curtain wall systems with the respect to all quantitative and qualitative criteria.

3.3.1.2 Multi-Criteria Decision-Making (MCDM) Techniques

The way decisions are made changed after computers started taking over after World War II. Many mathematical techniques were developed for assisting the decision-making process (Gaynor, 2015). The multi-criteria decision-making problems are related to determining the best alternative out of all other feasible alternatives in the presence of multiple criteria that are usually conflicting and having an influence the decision process (Kaya & Kahraman, 2014). These problems are related to multiple attributes. The attributes, usually decision criteria or goals, are considered to be representatives of different dimensions to view alternatives (Triantaphyllou, 2000). MCDM processes follow a common working principle including the following (Majumder, 2015):

- Criteria selection
- Alternatives selection
- Weighting methods selection for importance representation
- Aggregation method

Since the model is developed based on the viewpoint of the experts representing the engineering and architectural design firms, the selected technique should be appropriate for developing a questionnaire survey that can be filled easily by the experts and also provide the required data for developing the model. In this study, two MCDM techniques are considered for the design of the questionnaire survey which are the Analytic Hierarchy Process (AHP) and the Multi-Attribute Utility Theory (MAUT).

3.3.1.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a method that is used widely to solve multi-criteria decision-making problems. Qualitative and quantitative issues related to the problem are considered in evaluation processes (OECD, 2008). The development and documentation of the (AHP) was carried out Thomas Saaty in 1980 and it has different strengths including (Fellows & Liu, 2015):

- Complex decision problems can be decomposed into hierarchical sub-problems.
- Complex decision problems can be structured and analyzed in a versatile and powerful way
- A simple method that can be used.

(Darko et al., 2018) reviewed a total number of 77 AHP-based papers that were published during the period between 2004 and 2014. The reviewed papers were published in 8 peer-reviewed construction management journals. The review of these papers indicated the following:

- The most popular areas of AHP applications were found to be in risk management and construction sustainability.
- AHP has the flexibility to be used alone or integrated with other tools in order to solve a decision-making problems in the construction industry.
- AHP has a wide use in Asia.
- Using AHP was found to have common justifications including the following:
 - Small sample size
 - High consistency level
 - User-friendly software is available and simple

(Lam, Chan, Wong, & Wong, 2007) used the AHP for the purpose of deriving prioritized scales for the factors that affect the constructability and also for how common construction systems

relatively contribute to the superstructures of buildings which include frames of structures, slabs, interior walls, roofs, and envelopes toward the constructability.

(Hassanain, Assaf, Al-Hammad, & Al-Nehmi, 2015) applied the AHP in a study that aimed to develop an MCDM model that can be used by maintenance managers for considerations prior making decisions on outsourcing.

(Mohamed Marzouk & Abubakr, 2016) utilized the AHP to facilitate selecting the suitable type of tower crane in a study that aimed to develop a framework through the utilization of the Building Information Modeling (BIM) to plan for tower cranes in construction.

(Hosseini, Arefi, Bitarafan, Abazarlou, & Zavadskas, 2016) used AHP and fuzzy methods in a study that aimed to study different external wall alternatives for renewing and reconstructing buildings in earthquake locations.

(C.-J. Chen, Juan, & Hsu, 2017) used the AHP for the determination of the criteria weights in a study that aimed to propose a systematic approach for the evaluation and prediction of reasonable buildings' service life.

3.3.1.4 Multi-Attribute Utility Theory (MAUT)

The Multi-Attribute Utility Theory (MAUT) is one of the techniques supporting the decision-making process when the selection process is limited to a number of alternatives. The overall evaluation of each alternative is based on the addition of all weighted values of the alternative with respect to each considered attribute (Jansen, 2011). MAUT limits abilities of people conducting the evaluation due to its embracement of a large mathematical theory body for utility models and a wide range of practical evaluation techniques. Information obtained from the evaluation usually

feeds into the major problem for ranking of alternatives, making a choice, or clarifying situations for decision-makers (Dyer, Fishburn, Steuer, Wallenius, & Zionts, 1992). The combination of two or more of the MCDM techniques , such as AHP and MAUT, is recently a new trend that is considered for making up for shortcomings of any MCDM technique (Velasquez & Hester, 2013).

3.3.1.5 Application of AHP and MAUT in Construction

The combination the AHP and MAUT was adopted in different studies. (M Marzouk & Moselhi, 2003) utilized both of the MAUT and AHP to develop a decision support model for bidding in the construction industry which can help contractors to estimate the markup and also owners to evaluate bid proposals. (M. Marzouk, 2006) utilized the MAUT, AHP, and computer simulation for developing a selection model for equipment in earthmoving operations. (Abu Dabous & Alkass, 2010) utilized MAUT to propose a method of innovative ranking for bridge networks. AHP was utilized for extracting judgments related to the relative importance among different levels of each attribute. (Doczy & AbdelRazig, 2017) combined AHP and MAUT for the purpose of proposing a model optimizing the design selection of alternatives when the conflicting objectives of a project are given which include net-zero, LEED, and cost. (O. Alshamrani, Alshibani, & Alogaili, 2018) used the AHP and MAUT to develop an approach for the selection of lighting systems in residential buildings.

3.3.1.6 Questionnaire Sections

The data collection of this study is mainly divided into three parts in the questionnaire. The first part aims to have a background about respondents involved in the study. The purpose of the second part is to obtain weights of criteria through the AHP technique. The last part aims to evaluate the alternatives of curtain wall systems based on the MAUT so that utility scores of criteria can be

determined for all alternatives. Most of the questions in the survey are considered to be closed because they have predetermined sets of responses (Fellows & Liu, 2015).

A. General Information Section

Respondents are asked in this section to provide general information, such as the name and address of organizations they are working in, their technical background, and their years of experience. Respondents experienced curtain wall projects in office buildings were the only ones allowed to fill the questionnaire. This section aimed to have a background about the respondents' profile.

B. AHP Section

The development of the AHP section in the questionnaire survey was carried out for the purpose of obtaining weights of the identified criteria. Accordingly, a set of steps were identified in order to obtain the weight of criteria according the AHP method. The sequential order of those steps is presented below:

I. Problem Definition

In AHP, it is important that the decision problem, criteria of selection and alternatives are identified firstly (Temiz & Calis, 2017). The decision problem of this study is concerned with the selection of the most suitable curtain wall system for office buildings in Saudi Arabia. Both of the criteria of selection as well as the alternatives of curtain wall systems were identified through the literature review and interviews with local experts.

II. Development of the Structural Hierarchy

The development of the hierarchy is an essential step that aids in decomposing the complexity of the decision problem. This step requires organizing the criteria of selection in a structural hierarchy

at which the main goal of the decision problem, the selection of the most suitable curtain wall system in this study, is located on the highest level of the structural hierarchy. Then, the set of criteria are organized in different more levels in the hierarchy. The second level of the hierarchy consists of the secondary goals contributing to the achievement of main goal, the categorization of criteria into technical, economic, and socio-environmental in this study. The secondary goals, categories of criteria, are influenced by all criteria in sets located in a one level below the second one (Shapira & Simcha, 2009). Accordingly, all of the criteria are located below their associated categories.

III. Pairwise Comparison Matrices

After mapping the interrelationships among criteria in the structural hierarchy, the determination of their relative weights is carried out through pairwise comparisons among criteria within the same set (Shapira & Simcha, 2009). The decision-makers or experts utilize a scale that ranges from 1 to 9 in pairwise comparison matrices. The matrices are formed in which the preference of the expert is represented by $A = [a_{ij}]$ (A_i versus A_j for all of $i, j = 1, 2, 4, 5, \dots, n$) (Temiz & Calis, 2017). When two criteria are compared, it is important to determine the following (Shapira & Simcha, 2009):

- Which criterion is more important than the other or which one has a greater effect on the goal, main or secondary, that is one level higher in the structural hierarchy.
- What is the importance intensity associated with that criterion. The assessment of verbal intensities is carried out through translating them into the aforementioned scale.

The importance intensities associated with the scale used in pairwise comparisons and their descriptions are shown in Table 3.1 (Saaty & Vargas, 1994). If two criteria compared were found

to have an equal importance, a value of 1 is assigned to this comparison. If a criterion in a row were found to be more important than another one in a column, integers greater than 1 and less than or equal to 9 are assigned to such comparison. If criterion A is assigned an integer value of x when compared with criterion B, the criterion B the value of $1/x$, reciprocal value, when compared with criterion A (Shapira & Simcha, 2009). The pairwise comparison matrices enable experts to assess the contribution to the objectives associated with each single criterion in an independent manner. Therefore, this can aid in a simplification of the decision-making process (Doloi, 2008).

Table 3.1: The scale used in pairwise comparisons

Importance Intensity	Definition	Explanation
1	Equal Importance	Both of the compared activities have an equal contribution to the objective
2	Weak	
3	Moderate Importance	One activity is slightly favored over another based on the experience and judgement
4	Moderate Plus	
5	Strong Importance	One activity is strongly favored over another based on the experience and judgement
6	Strong Plus	
7	Very Strong/Demonstrated Importance	One activity is very strongly favored over another based on the experience and judgement
8	Very,very strong	
9	Extreme Importance	One activity is confirmed to have the highest possible priority over another
Reciprocals of the above numbers	When one of the above mentioned numbers is assigned to the comparison between activities i and j , the then the reciprocal of this numbers is assigned to the comparison between activities j and i .	

Source: (Saaty & Vargas, 1994)

IV. Relative-Weight Calculation

In AHP, the calculation of the relative weights of criteria is carried out based on deriving the Eigen values and Eigen vectors (Temiz & Calis, 2017). The Eigen vector of a pairwise comparison matrix is resulted from the comparison process. The relative weights of criteria compared with regard to

their categories located a level higher in the structural hierarchy are represented by the local priority vector (Shapira & Simcha, 2009). The computation of the Eigen vector is carried out through the normalizing pairwise comparison matrices (Doloi, 2008; Shapira & Simcha, 2009; Temiz & Calis, 2017). The Average of Normalized Columns (ANC) method was used in this study for the purpose of obtaining the Eigen values of a pairwise comparison matrix due to its high accuracy (Shapira & Simcha, 2009). The calculation of an Eigen value (relative weight) of a certain category of criteria or a single criterion in row i , which represents an element of the Eigen vector $\vec{w}$, is carried out by using the following equation:

$$w_i = \frac{1}{n} * \sum_{j=1}^n \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (3.1)$$

Where:

- **w_i :** Eigen value (relative weight) of a certain category of criteria or a single criterion in row i
- **n :** The size of the pairwise comparison matrix that have an n number of rows and columns
- **i :** Row number
- **j :** Column number
- **a_{ij} :** The element of the pairwise comparison matrix that is located in row i and columns j
- **a_{kj} :** The element located in row k of a normalized column j
- **Note:** (i, j , and $k = 1, 2, 3, \dots, n$)

V. Consistency Ratio (CR) Calculation

The consistency verification is one of the most essential steps in AHP. Since decision-makers are allowed to provide subjective judgments in the comparisons, it cannot be guaranteed that such judgments are consistent. Accordingly, the verification of the consistency is critical in order to ensure that the outcomes of the pairwise comparisons are optimized (Darko et al., 2018). Therefore, the consistency ratio (CR) is calculated for each pairwise comparison matrix in the

MCDM problem. This ratio represents a measure used to control the consistency of a comparison matrix. Based on various empirical studies, Saaty mentioned that the acceptable CR should have a value less than 0.1. Furthermore, it was recommended that inconsistent matrices, having CR more than 0.1, should be revised or the structural hierarchy should be rechecked (Shapira & Simcha, 2009). The inconsistency of a pairwise comparison matrix can be resulted from different factors such as lack of sufficient knowledge and also an inappropriately conceptualized structural hierarchy (Doloi, 2008). CR for a particular pairwise comparison matrix is calculated by dividing the consistency index (CI) by the random index (RI). CI of a matrix is calculated using the following equation (Saaty & Vargas, 1994):

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (3.2)$$

Where:

- **CI:** Consistency Index
- λ_{max} : Largest Eigen value
- **n:** Matrix size

RI value of a matrix depends on the matrix size (n) which is obtained from Table 3.2.

Table 3.2: Average random consistency index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: (Saaty & Vargas, 1994)

VI. Pairwise Matrices in the AHP Section

Based on a preliminary hierarchy of the problem, preliminary pairwise comparison matrices were established. Those matrices, aiming to obtain criteria weights, were used in the AHP section of the questionnaire to be tested in the pilot study.

C. MAUT Section

The utilization of utility functions is the MAUT foundation. Different criteria can be transformed into common dimensionless scales ranging from 0 to 1. The raw data of alternatives can be transformed to utility scores after creating utility function. MAUT and utility functions are utilized when quantitative data related to an alternative is known. The creation of utility graphs depends on each criterion's information. Each criterion considered in a MCDM problem has its own utility function (Baker et al., 2001). There is a difference between value and utility. The difference is as the following (Goodwin & Wright, 2000):

- Value: Scores related to decisions involving no risk elements and uncertainties.
- Utility: Scores related to decisions involving risks and uncertainties.

I. Bisection Method

The bisection is a method widely used for electing value functions and it requires the following steps (Goodwin & Wright, 2000):

1. The determination of highest and lowest values or best and worst values for the criteria.
2. Assigning a utility score of 1.0 for most preferred values (best values) and a utility score of zero to least preferred values (worst values)
3. The identification of midpoints value functions that lay in the center between best and worst values and then assigning a utility score of 0.5 to these points.

4. Assigning a utility score of 0.25 to the values of quarter points and also a utility score of 0.75 to the values that lay in the center between the best and midpoint values.
5. Plotting the graphs of value functions or attribute utilities after the determination of the five value points as shown in Figure 3.2.

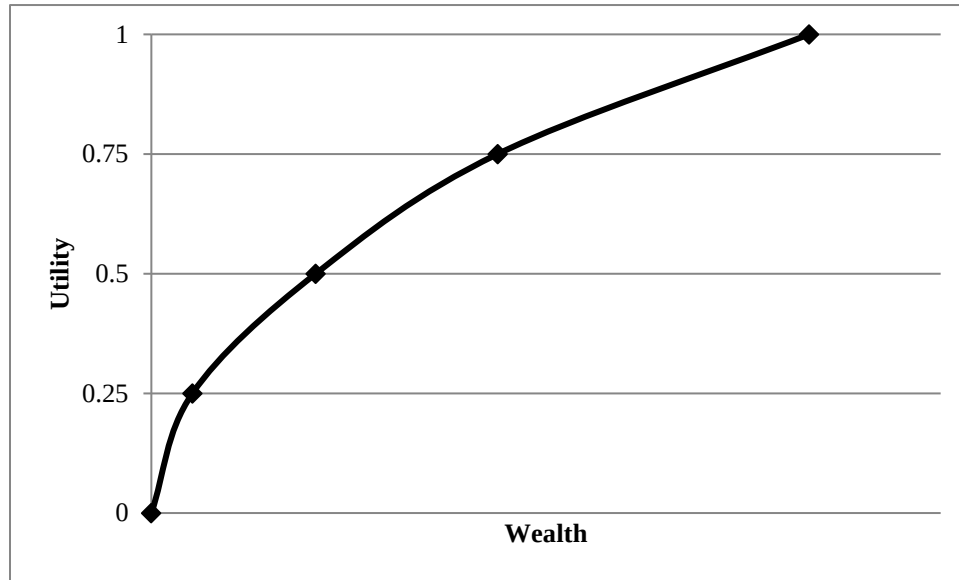


Figure 3.2: Utility function

These functions can provide utility scores for different quantitative criteria of. However, they cannot be developed for qualitative criteria, such as the aesthetics. Furthermore, the development of these functions for sum of the quantitative criteria cannot be easily carried out due to the uncertainty or unavailability of criteria values. Therefore, it is essential to look for a variant technique that can be used to obtain utility scores of all criteria.

II. Simple Multi Attribute Rating Technique (SMART)

The Simple Multi Attribute Rating Technique (SMART) can be used when actual information related to criteria is unavailable. Any convenient scale can be used to can be used to perform data normalization for defining utility functions. The most common points of scales used are 5, 7 or 10 (Baker et al., 2001). This can be considered as a non-comparative (metric) scaling technique for

collecting data from respondents. It requires an independent scaling of attributes or objects from others (Fellows & Liu, 2015). The considered scale in this study is a 5-point preference scale that ranges from 1 to 5. The scale 1 is assigned for the least preferred criterion which has a utility score of zero. Accordingly, the scale 5 is assigned for the most preferred criterion which has a utility score of 1. Scales of 2, 3 and 4 are utility scores of 0.25, 0.5, and 0.75, respectively (Baker et al., 2001). For non-comparative scales, the scale having brief descriptions of all categories is usually provided to the respondents (Fellows & Liu, 2015). Accordingly, Table 3.3 summarizes the 5 points and their descriptions. The MAUT section was developed according to the previous steps in order to assess utility scores for all criteria. The respondents were asked to provide the scale ranging from 1 to 5 for all considered curtain wall systems with respect to each criterion.

Table 3.3: Five-point scale of criteria (SMART)

Scale	Score	Description
1	0.00	Not Preferred (Least Preferred)
2	0.25	Preferred Somewhat
3	0.50	Moderately Preferred
4	0.75	Very Preferred
5	1.00	Extremely Preferred (Most Preferred)

3.3.2 Pilot-testing of the Questionnaire

Piloting the developed questionnaire is an important step that involves completing the questionnaire by few respondents in order to test the intelligibility and easiness of all questions by getting respondents' feedback. Hence, this can result in improving the developed questionnaire

(Fellows & Liu, 2015). In this study, the pilot surveys are sent to experts in design offices and consulting firms, prior their distributions to the targeted sample, for the purpose of:

- Reviewing the developed pairwise matrices among criteria considered in the AHP section in terms of the clarity and easiness to fill them.
- Reviewing the both of criteria and curtain wall alternatives to be evaluated in the MAUT section in terms of the clarity and easiness to fill them.

3.3.3 Data Collection

The distribution of the developed questionnaire to a representative sample of professionals working in design offices and consulting firms is involved in this stage. This aims at assessing the criteria weight as well as providing utility scores of criteria for all alternatives in AHP and MAUT sections, respectively. Surveys aim at producing information about entire populations. However, since the size of a population is very large, a sample size of that population is usually employed for the purpose of yielding sufficient reliable data used to draw inferences about that population at certain confidence level (Fellows & Liu, 2015). Accordingly to the review paper (Darko et al., 2018), the range of the sample size used in AHP analysis was between 4 and 9. Moreover, the number of studies having a sample size of 30 or more was limited. Therefore, the targeted sample size for the AHP section is similar to the MAUT. However, any inconsistent responses, having consistency ratio(s) more than 0.1, are excluded. The sample size of the respondents needed to complete the MAUT section consists of professionals working in design offices and consulting firms in the Eastern province of Saudi Arabia. The population size is obtained from Asharqia Chamber, the chambers of commerce located in Dammam city, which is one of the oldest Saudi organizations contributing to promote the role of private sector to the national economy (Asharqia

Chamber, 2019).The determination of the sample size is based on the following two equations (Kish, 1995):

$$n_0 = \frac{(p \times q)}{(v)^2} \quad (3.3)$$

$$n = \frac{n_0}{[1 + (\frac{n_0}{N})]} \quad (3.4)$$

Where:

- **n₀:** The first sample size estimate
- **p:** The characteristic population to be measured in targeted populations
- **q:** 1-p (the completion of p)
- **V:** The maximum allowable standard error percentage (set to be 10% in the study)
- **n:** The sample size
- **N:** The population size
- **Note:** p and q are set to be 0.5 for maximizing the sample

The total number of the design offices and consulting firms (A/E) registered in Alsharqia Chamber is 50. Therefore, the determination of the required sample size is as the following:

$$n_0 = \frac{(0.5) \times (1-0.5)}{0.1^2} = 25 \text{ respondents}$$

$$n = \frac{25}{1 + \frac{25}{50}} = 16.7 \approx 17 \text{ respondents}$$

However, the targeted sample size in the study is 30 in order to have more reliability.

3.3.4 Data Analysis

This stage involves analyzing the received data from distributed questionnaires. The analysis is performed on the three sections, namely general information, evaluation of criteria influencing the selection of curtain wall systems, and evaluation of different curtain wall systems using MAUT.

3.3.4.1 Respondents' Profile

The analysis of the first section is performed in order to obtain a background about the respondents' profile. Firstly, the analysis is performed on the technical background of the respondents in order to obtain their distributions. Then the distribution of the respondents' years of experience is secondly analyzed. Finally, the analysis is performed on the address of the organization in terms of the location of the city in the Eastern Province of Saudi Arabia.

3.3.4.2 Weight of Criteria

The analysis of the AHP section is based on calculating the consistency ratio for all pairwise comparison matrices. Respondents having inconsistent pairwise comparison matrices are excluded. The calculations of the relative weights as well as consistency ratios for each respondent are conducted by utilizing Expert Choice Software that is used to analyze AHP data (Dalalah, Al-Oqla, & Hayajneh, 2010; Darko et al., 2018; Erdogan, Šaparauskas, & Turskis, 2017; Temiz & Calis, 2017).

3.3.4.3 Utility Scores for Alternatives

The analysis of the MAUT section aims to obtain utility scores of criteria for all alternatives. The 5-point scale assigned by the respondents in the MAUT section, as shown in Table 3.3, is converted to utility scores.

3.3.5 Development and Implementation of an MCDM Model

The developed AHP/MAUT based model used to evaluate and rank curtain wall systems is based on the combination of the weight of all criteria as well as their associated utility scores. The following equations illustrated the model used to evaluate and rank curtain wall systems:

$$V_i(x) = \sum W_{AHP} U_{MAUT} = (W_{C1} * U_{C1} + W_{C2} * U_{C2} + \dots W_{Cn} * U_{Cn}) . \quad (3.5)$$

Where:

- **W_{AHP}:** The weight of a criterion obtained from the AHP section
- **U_{MAUT}:** The utility score of a criterion for an alternative obtained from the MAUT section
- **W_C:** AHP weight of criteria which is obtained based on calculating the mean of the consistent responses
- **U_C:** Utility score of criteria obtained based on calculating the mean of the responses
- **n:** The total number of criteria

3.4 Achievement of the Third Objective

“To implement the developed MCDM model in a prototype computer application”

This stage involves implementing the developed MCDM model in a prototype computer application. This aims to illustrate the use of the model during the early design stages of office buildings at which designers have not yet selected the curtain wall system to be used in the project.

3.4.1 Criteria for Selecting the Development Tool

There is a need for a tool to be considered in the development of the MCDM model in a prototype computer application. The selection of such tool should consider different features including the following:

- The availability of the tool
- The ability to conduct calculations in a short period of time

- The ability to be used in any operating system
- The ability to have a user-friendly interface

Accordingly, the computer application of the model is developed using Angular web framework and is deployed using Angular's localhost server and viewed from any web browser application on any operating system.

3.4.2 System's Architecture

The computer implementation of the model considers that the designer identifies the feasible wall systems that all are believed to be used in the project. The criteria weights are equal for all systems, which were obtained from the questionnaire survey. The variable parameter is the utility score of alternatives due the variations in the performances of products with respect to different criteria. Accordingly, the main input by designers are the number of wall alternatives to be evaluated, names of the alternatives to be evaluated, and the utility scores of each alternative based on SMART. The main functions of the application are as the following:

1. To evaluate each alternative independently based on the assigned scores from users.
2. To rank (sort) the total scores of the alternative from the highest to the lowest values.

The layout of the system is illustrated in Figure 3.3.

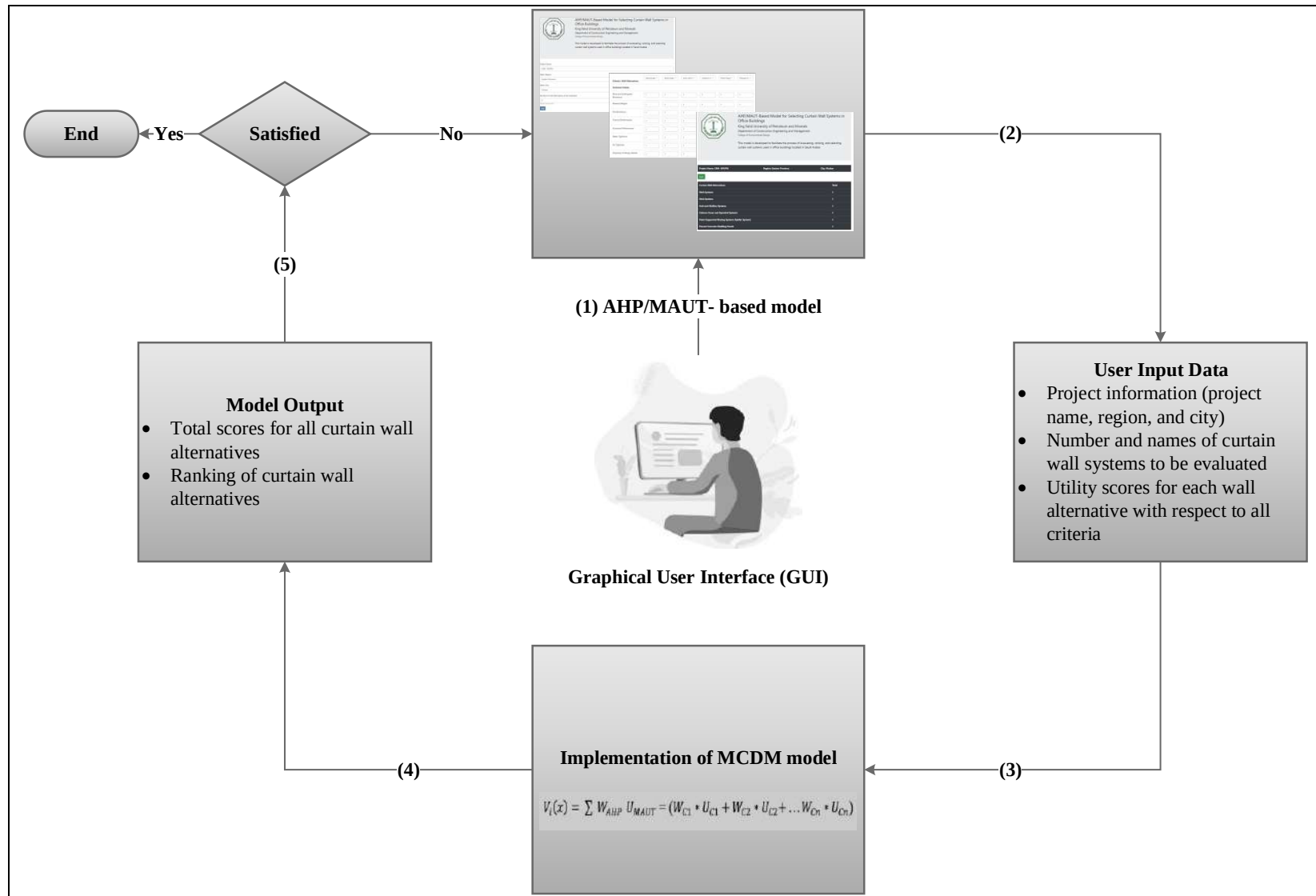


Figure 3.3: System Layout

3.4.3 Data Flow of the Developed Model

The model, in the early design stages, accepts data from the user and applies calculations done through the system and viewed back to the user, depending on the user's input and the weights assigned for each input. In the early design stages, the data required for the selection of the best curtain wall systems to be used in an office building is entered by users through a set of interface windows as well as retrieved from the local storage of the system. The data entered through a set of application inputs include the name of the project, number of walls to be evaluated, and the assigned scores for each alternative using SMART. Data retrieved from the database includes the region and the city of the project as well as the names of the curtain wall alternatives to be evaluated. Figure 3.4 illustrates the data flow of the model.

After completing input data, (including the project name, project location, number and names of walls to be evaluated, and the assigned scores for alternatives the alternatives with respect to different criteria), the independent evaluation for each wall alternative is involved in the next stage which is based on a multiplication of criteria weights that are saved in the application's local storage by their associated utility scores. Then, the total scores of the alternatives can be sorted from the highest to the lowest values.

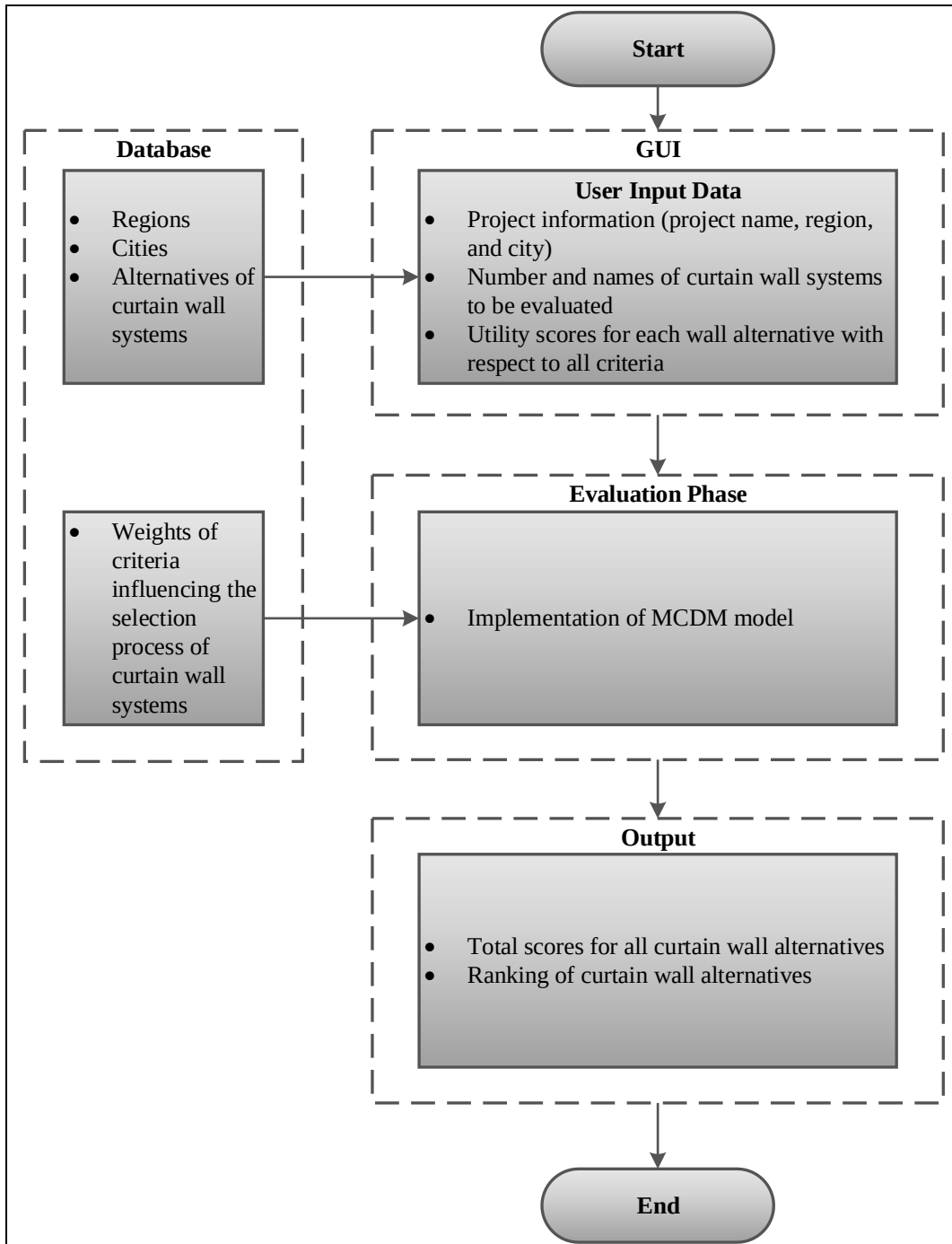


Figure 3.4: Data flow of the model

3.4.4 Graphical User Interface (GUI)

The graphical user interface of the model incorporates form inputs that are accepted by any browser and any operating system and then can be submitted through the browser itself to view the results back onto the user interface. The user interface is designed and coded in a way that facilitates (1) entering the project information that includes the project name, region and city, (2) number and name of the alternatives to be evaluated, and (3) the evaluation of each alternative with respect to all criteria.

3.4.5 Model Validation

The validation of any developed model is an important step that generally aims to determine the validity of the model results. In this research, the validation of the developed model is based on two stages. The first stage requires conducting structured interviews with local experts representing design offices and consulting firms who were involved in the design and selection of curtain wall systems used in office buildings located in the Eastern Province of Saudi Arabia. A questionnaire is administered in those interviews through asking a set of questions. The responses of interviewees are then recorded (Fellows & Liu, 2015). There are three main questions in those interviews which are related to (1) the selection of curtain wall systems that can be considered in an office building project, (2) evaluating the selected curtain wall systems, and (3) identifying the most preferred system and providing the reason for that.

In the second stage, the interviewees are asked to enter the evaluation data to the computer application. The results of implementing MCDM model are compared with initial decisions of the interviews.

3.4.6 Model Limitation

The limitations of this model are summarized as the following:

1. The weights of criteria are constant which are based on the data received from total of fourteen consistent responses
2. The model assumes only one system is used in the whole building

3.5 Summary

The chapter covers total of eight steps consternated to the achievement of the formulated objectives of this research. The first two steps are followed for achieving the first objective. The following five steps contribute to achieve the second objective. The third objective is achieved by the last step.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results associated with the sequential steps of the research methodology, which contribute to achieve the research objectives. Based on a comprehensive literature review and semi-structured interviews conducted with five local experts working in design offices, it was found that the stick systems, unitized systems, unit-and-mullion systems, column-cover-and spandrel systems, point-supported glazing systems, and precast concrete cladding panels were the most common systems used in office buildings located in the Eastern Province. Furthermore, there were some criteria removed and there were no additional criteria identified from local experts. Accordingly, a preliminary questionnaire survey was designed consisting of three sections, namely general information, evaluation of criteria influencing the selection of curtain wall systems, and evaluation of different curtain wall systems using MAUT. This questionnaire was used as a pilot survey that was sent to a total of five experts in design offices and consulting firms, prior its distribution to the targeted sample. The conducted pilot study resulted in modifications in some terminologies of criteria and curtain wall systems as well as division or combination of some criteria. Therefore, the finalized design of structural hierarchy in this study is shown in Figure 4.1 which consists of a total of 23 criteria categorized into three main groups. Appendices E and F show the finalized design of the questionnaire survey that including the three sections.

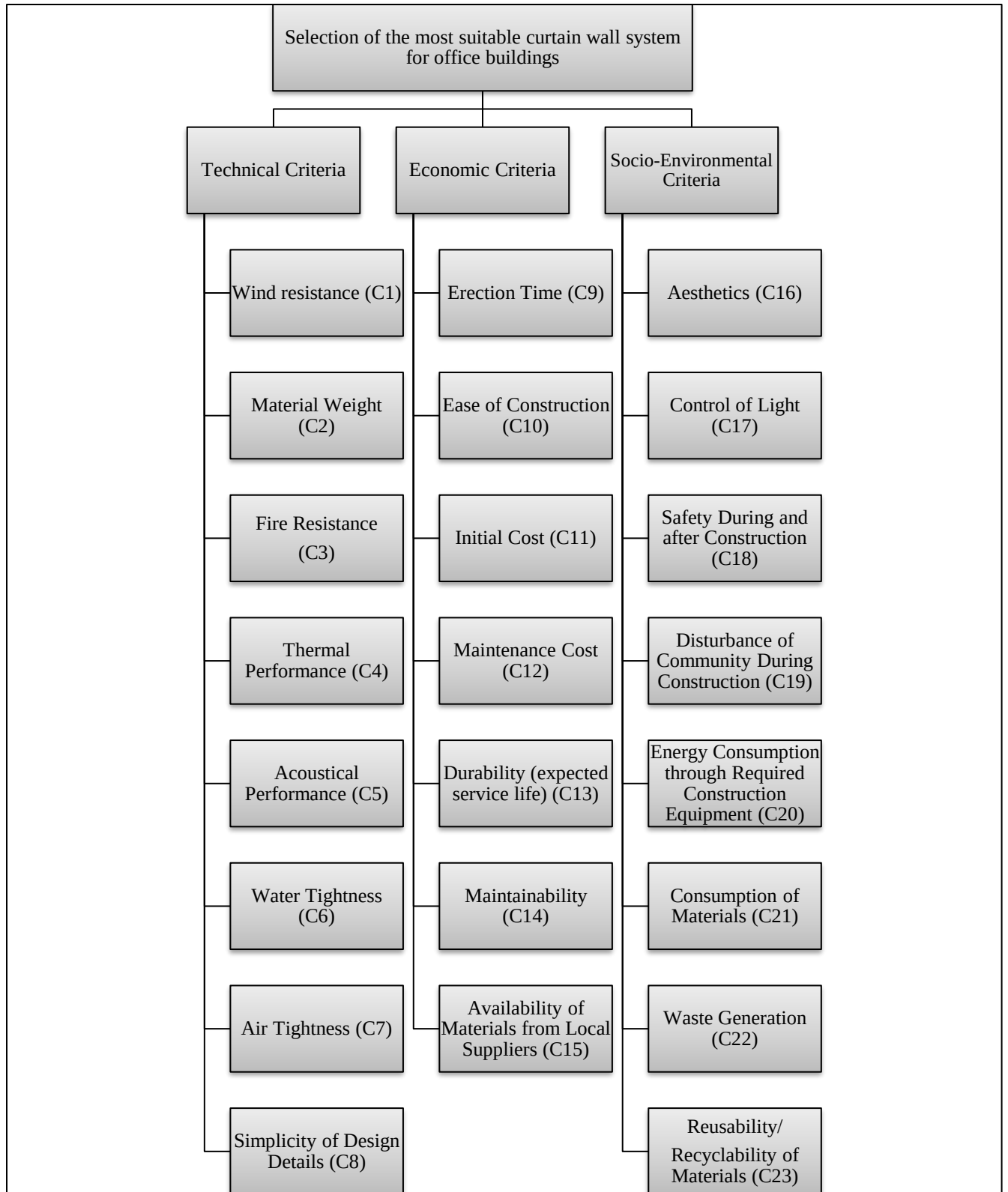


Figure 4.1: Finalized design of the structural hierarchy

4.2 Respondents' Profile

Total of 30 responses were collected from participants representing engineering and design consulting firms in the Eastern Province of Saudi Arabia. The participants are architects, architectural/building engineers, civil/construction engineers, mechanical and electrical engineers. This distribution technical background of responses is illustrated in Figure 4.2. The majority (73%) of participants have more than five years of experience in the building design. Figure 4.3 shows the participants' experience distribution. All participants have been involved in the section of curtain wall systems. The majority (67%) and the remaining (33%) of responses work in consulting firms which are located in Khobar and Dammam, respectively. Figure 4.4 illustrates the spatial distribution of respondents.

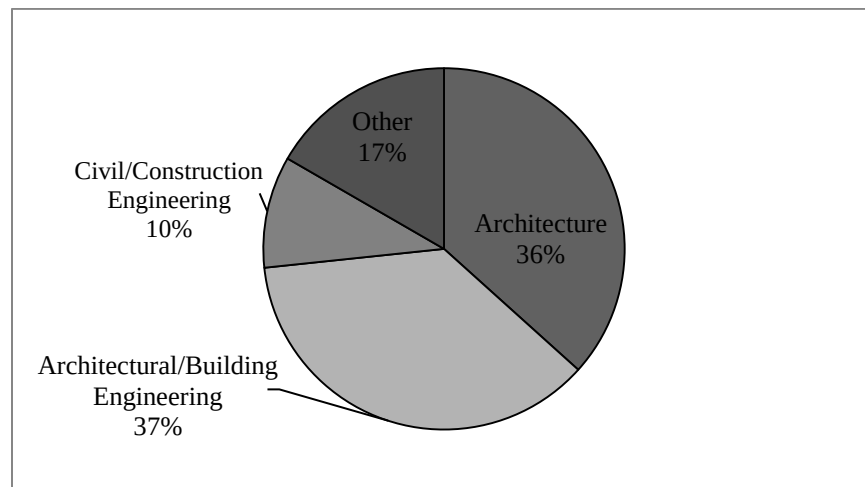


Figure 4.2: Technical background distribution of the respondents

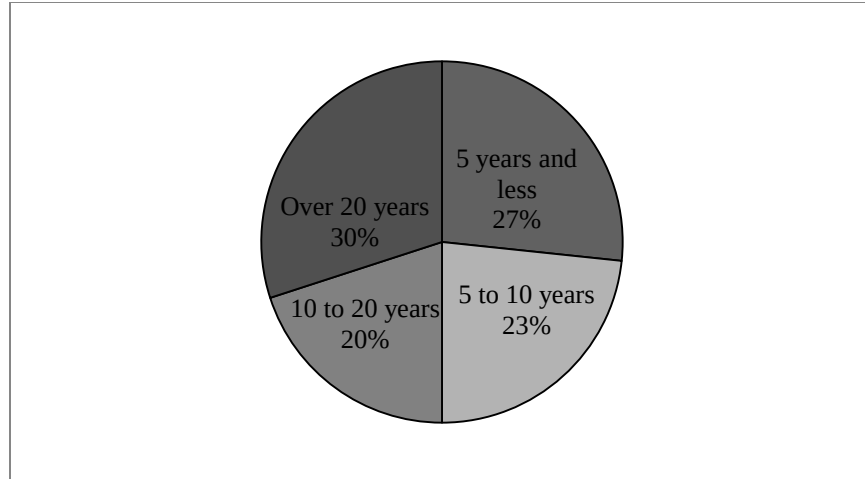


Figure 4.3: Distribution of respondents' years of experience

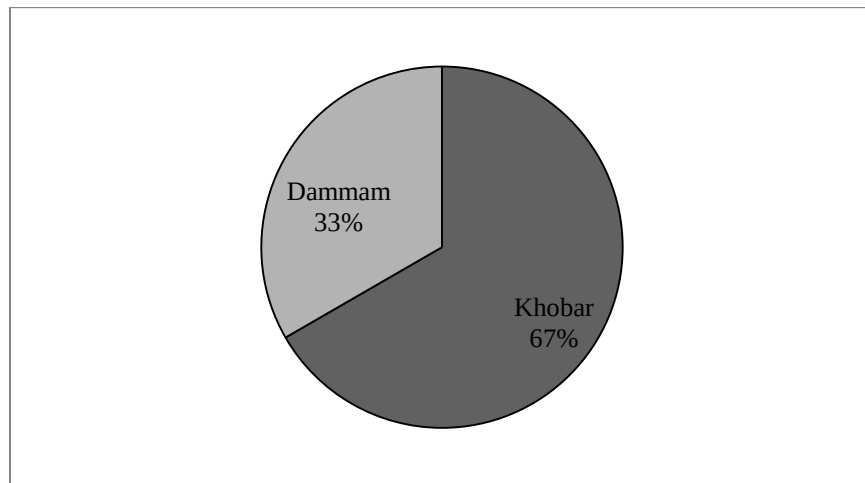


Figure 4.4: Spatial distribution of respondents

4.3 AHP Results

The analysis of AHP data aims at obtaining the weights of criteria. Expert Choice Software was used to analyze AHP data in order to calculate the relative weights as well as consistency ratios of the four matrices, as illustrated in Appendix G. The results reveal that there are a total of 14 respondents (out of 30) were consistent, which had CR less than 0.1. Accordingly, there are a total of 56 consistent pairwise comparison matrices (4 consistent pairwise comparison matrices for each

respondent). Tables 4.1 to 4.4 show the pairwise comparison matrices evaluated by the first consistent response. Both of the consistency ratios of matrices as well as the Eigen vectors, relative weights, pairwise comparison matrices were calculated by the software. The relative weights associated with the first consistent response are illustrated in figures 4.5 to 4.8. The sum of all relative weights of a certain matrix is equal to 1.0. The MCDM model considers the global weight of all 23 criteria. Therefore, the weight of a major criteria group was multiplied by criteria weights belonging to it in order to transform local weights of all the 23 criteria into global weights. The process of transforming the local weights calculated from the first respondent into global weights is illustrated in Table 4.5. The calculations of the consistency ratios, local weights, and global weights that are belonging to the remaining 13 consistent responses are presented in Appendix H. The finalized global weights of criteria obtained from all 14 consistent responses are summarized in Table 4.6. The mean of the weights was calculated in order to be used in the MCDM model presented.

Table 4.1: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 1

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1	3
Economic Criteria		1	2
Socio-Environmental Criteria			1
CR = 0.02			

Table 4.2: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 1

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	2	3	2	2	1	2	2
Material Weight		1	1/2	1/2	1/2	1/2	1/2	1
Fire Resistance			1	2	2	2	3	1
Thermal Performance				1	2	1	1	1
Acoustical Performance					1	1	1	1
Water Tightness						1	1	1
Air Tightness							1	1
Simplicity of Design Details								1
CR = 0.04								

Table 4.3: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 1

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	3	1	3	1/3	1/3	1/3
Ease of Construction		1	1	1	1/3	1/3	1/3
Initial Cost			1	3	1	1/3	1/3
Maintenance Cost				1	½	1	1/3
Durability (expected service life)					1	2	1
Maintainability						1	1/2
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table 4.4: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 1

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1/2	1/2	3	2	2	2
Control of Light		1	1/3	1/3	2	1	3	2
Safety During and after Construction			1	1	2	3	2	2
Disturbance of Community During Construction				1	2	2	2	2
Energy Consumption through Required Construction Equipment					1	½	2	2
Consumption of Materials						1	2	2
Waste Generation							1	1/2
Reusability/Recyclability of Materials								1
CR = 0.05								

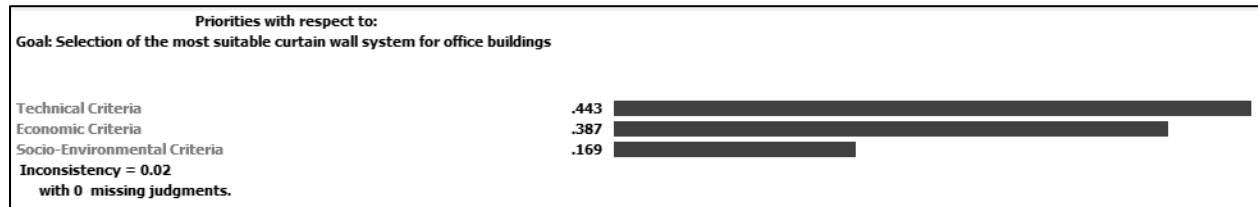


Figure 4.5: Weights of major criteria group and the consistency ratio obtained from the first consistent respondent

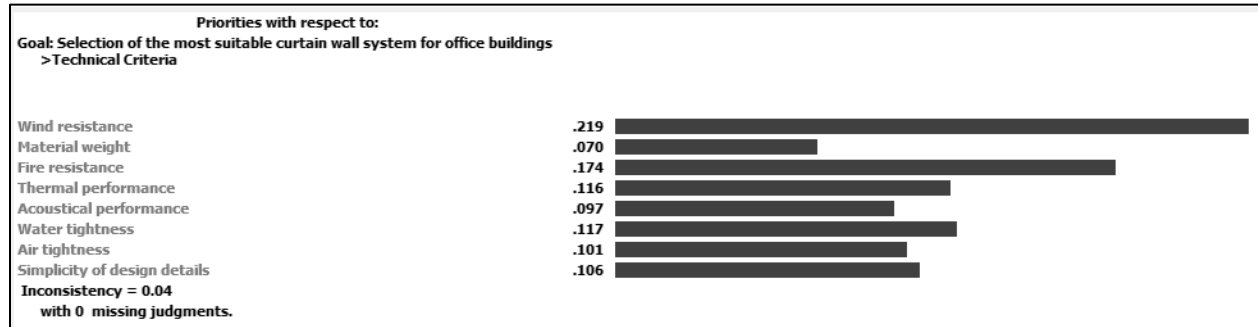


Figure 4.6: Weights of technical criteria and the consistency ratio obtained from the first consistent respondent

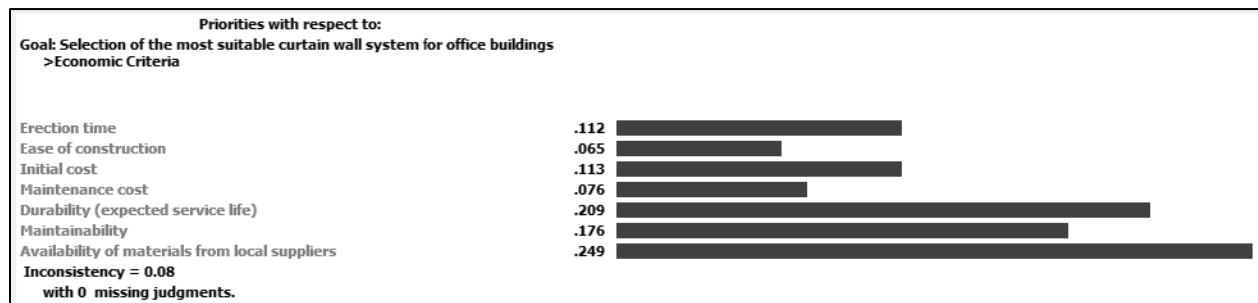


Figure 4.7: Weights of economic criteria and the consistency ratio obtained from the first consistent respondent

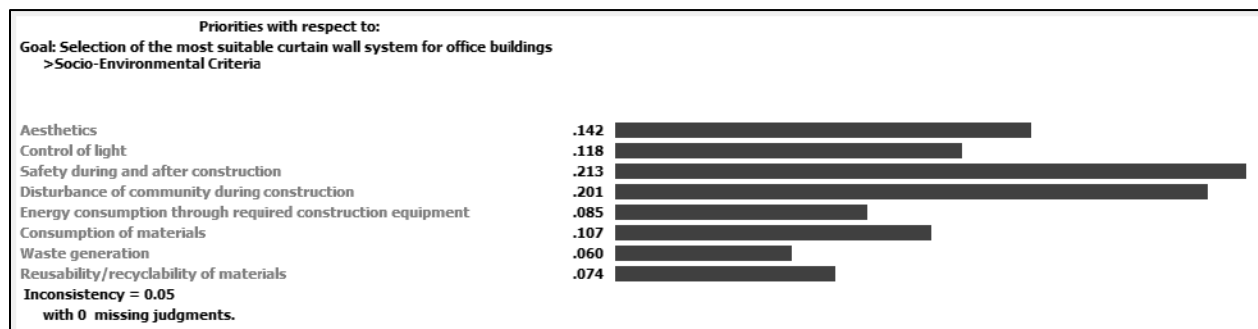


Figure 4.8: Weights of socio-environmental criteria and the consistency ratio obtained from the first consistent respondent

Table 4.5: Weight of criteria obtained from respondent No. 1

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.443	Wind Resistance	0.219	0.097
		Material Weight	0.070	0.031
		Fire Resistance	0.174	0.077
		Thermal Performance	0.116	0.051
		Acoustical Performance	0.097	0.043
		Water Tightness	0.117	0.052
		Air Tightness	0.101	0.045
		Simplicity of Design Details	0.106	0.047
		Total	1.000	0.443
Economic Criteria	0.387	Erection Time	0.112	0.043
		Ease of Construction	0.065	0.025
		Initial Cost	0.113	0.044
		Maintenance Cost	0.076	0.029
		Durability (expected service life)	0.209	0.081
		Maintainability	0.176	0.068
		Availability of Materials from Local Suppliers	0.249	0.096
		Total	1.000	0.387
Socio-Environmental Criteria	0.169	Aesthetics	0.142	0.024
		Control of Light	0.118	0.020
		Safety During and after Construction	0.213	0.036
		Disturbance of Community During Construction	0.201	0.034
		Energy Consumption through Required Construction Equipment	0.085	0.014
		Consumption of Materials	0.107	0.018
		Waste Generation	0.060	0.010
		Reusability/Recyclability of materials	0.074	0.013
Total	0.990	Total	1.000	0.169

Table 4.6: Weight of criteria according to the AHP section

Category	Criteria	Weight of Criteria According to the Respondent No.														Mean
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Technical Criteria	Wind Resistance	0.097	0.120	0.045	0.159	0.167	0.064	0.043	0.042	0.108	0.182	0.057	0.083	0.074	0.042	0.092
	Material Weight	0.031	0.020	0.010	0.058	0.019	0.021	0.023	0.014	0.015	0.024	0.047	0.028	0.026	0.017	0.025
	Fire Resistance	0.077	0.151	0.055	0.099	0.079	0.057	0.040	0.075	0.239	0.122	0.102	0.161	0.104	0.084	0.103
	Thermal Performance	0.051	0.061	0.046	0.056	0.033	0.065	0.057	0.040	0.041	0.079	0.067	0.052	0.094	0.058	0.057
	Acoustical Performance	0.043	0.028	0.014	0.078	0.037	0.033	0.052	0.033	0.023	0.043	0.042	0.052	0.062	0.024	0.040
	Water Tightness	0.052	0.066	0.033	0.023	0.044	0.082	0.049	0.021	0.082	0.066	0.079	0.052	0.051	0.047	0.053
	Air Tightness	0.045	0.066	0.014	0.029	0.044	0.066	0.046	0.031	0.071	0.056	0.038	0.052	0.051	0.026	0.045
	Simplicity of Design Details	0.047	0.035	0.009	0.027	0.022	0.041	0.018	0.076	0.034	0.041	0.033	0.014	0.032	0.015	0.032

Table 4.6: Weight of criteria according to the AHP section (Cont.)

Category	Criteria	Weight of Criteria According to the Respondent No.														Mean
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Economic Criteria	Erection Time	0.043	0.013	0.075	0.024	0.032	0.039	0.027	0.063	0.018	0.022	0.044	0.016	0.015	0.009	0.031
	Ease of Construction	0.025	0.014	0.018	0.041	0.043	0.057	0.035	0.053	0.012	0.024	0.059	0.017	0.024	0.012	0.031
	Initial Cost	0.044	0.021	0.095	0.040	0.061	0.053	0.024	0.094	0.029	0.074	0.082	0.029	0.015	0.020	0.049
	Maintenance Cost	0.029	0.037	0.100	0.055	0.079	0.064	0.029	0.086	0.016	0.049	0.045	0.050	0.037	0.035	0.051
	Durability (expected service life)	0.081	0.093	0.219	0.087	0.095	0.077	0.071	0.056	0.011	0.045	0.076	0.044	0.040	0.054	0.075
	Maintainability	0.068	0.063	0.080	0.053	0.091	0.070	0.047	0.104	0.009	0.037	0.076	0.053	0.040	0.034	0.059
	Availability of Materials from Local Suppliers	0.096	0.104	0.086	0.033	0.043	0.068	0.027	0.136	0.021	0.017	0.049	0.102	0.026	0.033	0.060

Table 4.6: Weight of criteria according to the AHP section (Cont.)

Category	Criteria	Weight of Criteria According to the Respondent No.														Mean
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Socio-Environmental Criteria	Aesthetics	0.024	0.008	0.020	0.014	0.014	0.021	0.071	0.004	0.022	0.016	0.010	0.033	0.044	0.041	0.024
	Control of Light	0.020	0.015	0.016	0.021	0.022	0.013	0.069	0.004	0.038	0.014	0.029	0.033	0.048	0.071	0.030
	Safety During and after Construction	0.036	0.052	0.023	0.026	0.039	0.029	0.041	0.007	0.067	0.031	0.006	0.091	0.068	0.141	0.047
	Disturbance of Community During Construction	0.034	0.005	0.013	0.011	0.009	0.016	0.031	0.008	0.016	0.006	0.004	0.007	0.021	0.045	0.016
	Energy Consumption through Required Construction Equipment	0.014	0.007	0.008	0.013	0.004	0.020	0.051	0.011	0.028	0.017	0.010	0.007	0.023	0.039	0.018
	Consumption of Materials	0.018	0.011	0.008	0.021	0.009	0.019	0.048	0.018	0.029	0.014	0.013	0.008	0.021	0.045	0.020
	Waste Generation	0.010	0.008	0.007	0.013	0.008	0.016	0.033	0.010	0.023	0.011	0.015	0.010	0.020	0.072	0.018
	Reusability/Recyclability of materials	0.013	0.004	0.006	0.021	0.006	0.010	0.068	0.014	0.045	0.007	0.014	0.007	0.065	0.038	0.023

The mean of the global weights was ordered in a descending order in the following tables for the purpose of having an insight into the data. Table 4.7 provides the descending order of technical criteria weights. The descending order of the economic and socio-environmental criteria weights is shown in Table 4.8 and Table 4.9, respectively. Table 4.10 show the descending order of all weights of criteria.

The fire resistance obtained the highest weight among the other technical criteria and it also has the highest weight among all weights of criteria as indicated in Table 4.7 and Table 4.10, respectively. This is due to the fact that the Eastern Province Municipality has obliged its accredited engineering and design offices to ensure the safety of designs for the prevention and protection from fires as well as the use of fire-resistant materials, especially in cladding facades. In addition, it obliged them to comply the architectural drawings with the Saudi Fire Code on all buildings. This came as a result of the discovery of the presence of non-fire-resistant materials in the fire accident sites of buildings or the installation of materials in a way that does not help to reduce the spread of fire (Al-Mulla, 2019a). The Saudi Standards, Metrology and Quality Organization (SASO) requires traders and suppliers to register products subject to the technical regulations of building materials, including insulation materials and building cladding materials, in the Saber electronic platform. This requirement is a prerequisite of the materials to enter the Saudi market and allow their circulation in order to raise the level of product safety (Al-Mulla, 2019b). The wind resistance obtained the second highest weight among other technical criteria as well as all among all weights of criteria as shown in Table 4.7 and Table 4.10, respectively. This indicates that the structural safety associated with such building system is an important consideration that ensures a proper serviceability of the curtain walls during its service life, especially for high-rise buildings.

The durability (expected service life) obtained the highest weight among the other economic criteria, as shown in Table 4.8. Table 4.10 indicates that it has the third highest weight among all criteria weights. This because it has a vital role on tolerating severe exterior exposure conditions as well as formation of defects during the service life of curtain wall systems. One of the major considerations taken by practitioners is to have curtain wall systems that consist of materials having proper resistance to harsh weathering conditions. This can contribute in minimizing the probabilities of having defects in curtain wall systems during their service lives. The availability of materials from local suppliers obtained the second highest weight among other economic criteria as shown in Table 4.8. It has the fourth highest weight among all criteria weights. This due to the fact that using building materials and systems supplied locally can aid in the minimization of projects' total costs and durations. Importing building materials or systems from external suppliers generally requires longer transportation distances which have considerable effects on cost and time.

Regarding the socio-environmental criteria, the safety during and after construction scored the highest weight among the others. This is due to the importance of minimizing probabilities of having injuries that might be resulted from any construction activity. Furthermore, the selection of building elements and materials that ensures the security of occupants is one of the major considerations associated with design of buildings, especially for high-rise buildings. According to Table 4.10, the highest 9 weights of criteria were found to technical and economic criteria. This indicates that many local practitioners give higher priorities to the technical performance of curtain wall systems as well as the economic aspects associated with them.

Table 4.7: Descending order of technical criteria weights

Criteria	Criteria Weight (W)
Fire Resistance (C3)	0.103
Wind Resistance (C1)	0.092
Thermal Performance (C4)	0.057
Water Tightness (C6)	0.053
Air Tightness (C7)	0.045
Acoustical Performance (C5)	0.040
Simplicity of Design Details (C8)	0.032
Material Weight (C2)	0.025

Table 4.8: Descending order of economic criteria weights

Criteria	Criteria Weight (W)
Durability (expected service life) (C13)	0.075
Availability of Materials from Local Suppliers (C15)	0.060
Maintainability (C14)	0.059
Maintenance Cost (C12)	0.051
Initial Cost (C11)	0.049
Erection Time (C9)	0.031
Ease of Construction (C10)	0.031

Table 4.9: Descending order of socio-environmental criteria weights

Criteria	Criteria Weight (W)
Safety During and after Construction (C18)	0.047
Control of Light (C17)	0.030
Aesthetics (C16)	0.024
Reusability/Recyclability of materials (C23)	0.023
Consumption of Materials (C21)	0.020
Waste Generation (C22)	0.018
Energy Consumption through Required Construction Equipment (C20)	0.018
Disturbance of Community During Construction (C19)	0.016

Table 4.10: Descending order of all weights of criteria

Criteria	Category	Criteria Weight (W)
Fire Resistance (C3)	Technical Criteria	0.103
Wind Resistance (C1)	Technical Criteria	0.092
Durability (expected service life) (C13)	Economic Criteria	0.075
Availability of Materials from Local Suppliers (C15)	Economic Criteria	0.060
Maintainability (C14)	Economic Criteria	0.059
Thermal Performance (C4)	Technical Criteria	0.057
Water Tightness (C6)	Technical Criteria	0.053
Maintenance Cost (C12)	Economic Criteria	0.051
Initial Cost (C11)	Economic Criteria	0.049
Safety During and after Construction (C18)	Socio-Environmental Criteria	0.047
Air Tightness (C7)	Technical Criteria	0.045
Acoustical Performance (C5)	Technical Criteria	0.040
Simplicity of Design Details (C8)	Technical Criteria	0.032
Erection Time (C9)	Economic Criteria	0.031
Ease of Construction (C10)	Economic Criteria	0.031
Control of Light (C17)	Socio-Environmental Criteria	0.030
Material Weight (C2)	Technical Criteria	0.025
Aesthetics (C16)	Socio-Environmental Criteria	0.024
Reusability/Recyclability of materials (C23)	Socio-Environmental Criteria	0.023
Consumption of Materials (C21)	Socio-Environmental Criteria	0.020
Waste Generation (C22)	Socio-Environmental Criteria	0.018
Energy Consumption through Required Construction Equipment (C20)	Socio-Environmental Criteria	0.018
Disturbance of Community During Construction (C19)	Socio-Environmental Criteria	0.016

4.4 MAUT Results

The analysis of the third section aims at obtaining utility scores of criteria for each curtain wall system. This was carried out through determining the frequency of the 5-point scale assigned by the respondents to the curtain wall systems. After that, the frequency of each scale was converted to a frequency of utility score considering the corresponding scores of scales presented in Table 3.3. Accordingly, the final score for each criterion for a certain alternative was calculated based on calculating the mean of utility score. The mean of those scores was calculated in order to be used in the MCDM model. Tables 4.11 to 4.16 illustrate the frequencies of utility scores of criteria for all curtain wall systems and the calculated mean, which were obtained from the 30 respondents.

Table 4.11: Utility scores for stick systems

Category	Criteria	Frequency of the Utility Scores for Stick Systems					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	5	9	6	8	2	30	0.442
	Material Weight	3	5	9	7	6	30	0.567
	Fire Resistance	7	9	10	1	3	30	0.367
	Thermal Performance	2	9	13	4	2	30	0.458
	Acoustical Performance	1	8	13	6	2	30	0.500
	Water Tightness	1	6	12	10	1	30	0.533
	Air Tightness	1	5	12	10	2	30	0.558
	Simplicity of Design Details	3	2	9	11	5	30	0.608
Economic Criteria	Erection Time	2	9	11	4	4	30	0.492
	Ease of Construction	0	12	8	6	4	30	0.517
	Initial Cost	1	7	9	10	3	30	0.558
	Maintenance Cost	3	5	10	8	4	30	0.542
	Durability (expected service life)	1	4	20	4	1	30	0.500
	Maintainability	5	5	8	7	5	30	0.517
	Availability of Materials from Local Suppliers	1	1	6	12	10	30	0.742
Socio-Environmental Criteria	Aesthetics	2	2	7	7	12	30	0.708
	Control of Light	0	2	17	6	5	30	0.617
	Safety During and after Construction	1	8	11	6	4	30	0.533
	Disturbance of Community During Construction	4	5	7	11	3	30	0.533
	Energy Consumption through Required Construction Equipment	2	7	11	9	1	30	0.500
	Consumption of Materials	1	3	16	8	2	30	0.558
	Waste Generation	1	10	13	4	2	30	0.467
	Reusability/Recyclability of materials	3	9	8	5	5	30	0.500

Table 4.12: Utility scores for unitized systems

Category	Criteria	Frequency of the Utility Score for Unitized Systems					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	1	3	15	8	3	30	0.575
	Material Weight	0	7	11	9	3	30	0.567
	Fire Resistance	2	7	14	5	2	30	0.483
	Thermal Performance	1	2	11	12	4	30	0.633
	Acoustical Performance	0	6	10	11	3	30	0.592
	Water Tightness	1	3	12	11	3	30	0.600
	Air Tightness	0	1	12	12	5	30	0.675
	Simplicity of Design Details	2	4	15	6	3	30	0.533
Economic Criteria	Erection Time	0	1	12	10	7	30	0.692
	Ease of Construction	1	6	9	11	3	30	0.575
	Initial Cost	2	6	12	7	3	30	0.525
	Maintenance Cost	2	8	13	7	0	30	0.458
	Durability (expected service life)	0	1	16	13	0	30	0.600
	Maintainability	1	9	10	10	0	30	0.492
	Availability of Materials from Local Suppliers	2	2	8	11	7	30	0.658
Socio-Environmental Criteria	Aesthetics	1	2	9	15	3	30	0.642
	Control of Light	1	3	13	8	5	30	0.608
	Safety During and after Construction	1	5	13	7	4	30	0.567
	Disturbance of Community During Construction	1	4	6	14	5	30	0.650
	Energy Consumption through Required Construction Equipment	1	6	12	9	2	30	0.542
	Consumption of Materials	0	5	13	11	1	30	0.567
	Waste Generation	1	4	10	13	2	30	0.592
	Reusability/Recyclability of materials	3	12	6	7	2	30	0.442

Table 4.13: Utility scores for unit-and-mullion systems

Category	Criteria	Frequency of the Utility Score for Unit-and-Mullion Systems					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	1	3	14	9	3	30	0.583
	Material Weight	1	6	14	6	3	30	0.533
	Fire Resistance	4	7	13	4	2	30	0.442
	Thermal Performance	0	6	13	7	4	30	0.575
	Acoustical Performance	2	5	10	9	4	30	0.567
	Water Tightness	0	3	15	9	3	30	0.600
	Air Tightness	0	2	13	9	6	30	0.658
	Simplicity of Design Details	4	5	12	8	1	30	0.475
Economic Criteria	Erection Time	1	8	9	10	2	30	0.533
	Ease of Construction	1	5	12	11	1	30	0.550
	Initial Cost	1	8	13	8	0	30	0.483
	Maintenance Cost	2	9	15	3	1	30	0.433
	Durability (expected service life)	1	6	16	6	1	30	0.500
	Maintainability	2	7	14	7	0	30	0.467
	Availability of Materials from Local Suppliers	3	2	8	13	4	30	0.608
Socio-Environmental Criteria	Aesthetics	1	1	14	9	5	30	0.633
	Control of Light	0	5	14	7	4	30	0.583
	Safety During and after Construction	2	3	14	6	5	30	0.575
	Disturbance of Community During Construction	1	4	11	10	4	30	0.600
	Energy Consumption through Required Construction Equipment	2	6	15	6	1	30	0.483
	Consumption of Materials	2	4	14	8	2	30	0.533
	Waste Generation	3	5	13	6	3	30	0.508
	Reusability/Recyclability of materials	5	8	7	8	2	30	0.450

Table 4.14: Utility scores for column-cover and spandrel systems

Category	Criteria	Frequency of the Utility Score for Column-Cover and Spandrel Systems					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	0	9	8	9	4	30	0.567
	Material Weight	2	6	15	3	4	30	0.508
	Fire Resistance	4	6	11	9	0	30	0.458
	Thermal Performance	0	7	11	12	0	30	0.542
	Acoustical Performance	1	6	11	11	1	30	0.542
	Water Tightness	1	3	12	13	1	30	0.583
	Air Tightness	1	3	12	10	4	30	0.608
	Simplicity of Design Details	4	2	9	11	4	30	0.575
Economic Criteria	Erection Time	2	4	6	12	6	30	0.633
	Ease of Construction	2	4	7	13	4	30	0.608
	Initial Cost	0	7	12	9	2	30	0.550
	Maintenance Cost	1	7	15	6	1	30	0.492
	Durability (expected service life)	1	4	14	11	0	30	0.542
	Maintainability	2	8	11	7	2	30	0.492
	Availability of Materials from Local Suppliers	3	3	8	12	4	30	0.592
Socio-Environmental Criteria	Aesthetics	0	4	10	10	6	30	0.650
	Control of Light	1	3	8	13	5	30	0.650
	Safety During and after Construction	1	4	15	8	2	30	0.550
	Disturbance of Community During Construction	0	5	8	13	4	30	0.633
	Energy Consumption through Required Construction Equipment	0	5	12	12	1	30	0.575
	Consumption of Materials	0	5	14	9	2	30	0.567
	Waste Generation	3	6	14	6	1	30	0.467
	Reusability/Recyclability of materials	3	14	8	3	2	30	0.392

Table 4.15: Utility scores for point-supported glazing systems (Spider System)

Category	Criteria	Frequency of the Utility Score for Point-Supported Glazing Systems (Spider System)					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	8	10	11	1	0	30	0.292
	Material Weight	0	10	4	12	4	30	0.583
	Fire Resistance	10	11	6	3	0	30	0.267
	Thermal Performance	7	9	8	5	1	30	0.367
	Acoustical Performance	6	10	9	5	0	30	0.358
	Water Tightness	2	7	16	4	1	30	0.458
	Air Tightness	2	9	14	4	1	30	0.442
	Simplicity of Design Details	2	7	5	6	10	30	0.625
Economic Criteria	Erection Time	2	3	8	10	7	30	0.642
	Ease of Construction	1	5	5	11	8	30	0.667
	Initial Cost	1	3	13	8	5	30	0.608
	Maintenance Cost	3	9	6	8	4	30	0.508
	Durability (expected service life)	2	9	11	5	3	30	0.483
	Maintainability	3	8	7	8	4	30	0.517
	Availability of Materials from Local Suppliers	1	3	7	10	9	30	0.692
Socio-Environmental Criteria	Aesthetics	0	1	5	6	18	30	0.842
	Control of Light	3	9	7	7	4	30	0.500
	Safety During and after Construction	3	11	11	5	0	30	0.400
	Disturbance of Community During Construction	2	5	7	14	2	30	0.575
	Energy Consumption through Required Construction Equipment	0	6	11	11	2	30	0.575
	Consumption of Materials	1	3	12	11	3	30	0.600
	Waste Generation	1	8	9	8	4	30	0.550
	Reusability/Recyclability of materials	7	8	6	4	5	30	0.433

Table 4.16: Utility scores for precast concrete cladding panels

Category	Criteria	Frequency of the Utility Score for Precast Concrete Cladding Panels					Total	Mean
		0.00	0.25	0.50	0.75	1.00		
Technical Criteria	Wind Resistance	2	4	7	9	8	30	0.642
	Material Weight	8	13	5	4	0	30	0.292
	Fire Resistance	3	1	4	12	10	30	0.708
	Thermal Performance	3	0	7	14	6	30	0.667
	Acoustical Performance	1	3	9	10	7	30	0.658
	Water Tightness	2	2	7	12	7	30	0.667
	Air Tightness	2	1	7	11	9	30	0.700
	Simplicity of Design Details	1	7	9	8	5	30	0.575
Economic Criteria	Erection Time	1	5	6	10	8	30	0.658
	Ease of Construction	1	6	8	9	6	30	0.608
	Initial Cost	1	10	7	9	3	30	0.525
	Maintenance Cost	2	8	8	5	7	30	0.558
	Durability (expected service life)	2	0	1	13	14	30	0.808
	Maintainability	1	9	9	4	7	30	0.558
	Availability of Materials from Local Suppliers	1	2	6	10	11	30	0.733
Socio-Environmental Criteria	Aesthetics	2	6	9	9	4	30	0.558
	Control of Light	6	4	6	13	1	30	0.492
	Safety During and after Construction	1	9	8	6	6	30	0.558
	Disturbance of Community During Construction	4	5	10	4	7	30	0.542
	Energy Consumption through Required Construction Equipment	5	8	7	7	3	30	0.458
	Consumption of Materials	1	9	7	9	4	30	0.550
	Waste Generation	2	4	8	10	6	30	0.617
	Reusability/Recyclability of materials	10	12	3	2	3	30	0.300

The mean of the utility scores of curtain wall alternatives obtained from the 30 responses which were associated with criteria having the highest three global weights, ranging from 0.08 to 0.1 as presented in Table 4.10, were ordered in a descending order in the following tables for the purpose of having an insight into the data. Tables 4.17, 4.18, and 4.19 provide the descending order of the utility scores for the curtain wall alternatives for the fire resistance, wind resistance, and durability, respectively.

The precast concrete cladding panels obtained the highest score in these three criteria. The utilized systems had the second highest score in both of the fire resistance and the durability. The unit-and-mullion systems obtained the second highest score in the wind resistance. The column-cover and spandrel systems had the third highest score in both of the fire resistance and the durability. The point-supported glazing systems (spider system) obtained the lowest score in all of the three criteria.

.

Table 4.17: Descending order of the fire resistance utility scores

Curtain Wall Alternative	Utility Score (U)
Precast Concrete Cladding Panels	0.708
Unitized Systems	0.483
Column-Cover and Spandrel Systems	0.458
Unit-and-Mullion Systems	0.442
Stick Systems	0.367
Point-Supported Glazing Systems (Spider System)	0.267

Table 4.18: Descending order of the wind resistance utility scores

Curtain Wall Alternative	Utility Score (U)
Precast Concrete Cladding Panels	0.642
Unit-and-Mullion Systems	0.583
Unitized Systems	0.575
Column-Cover and Spandrel Systems	0.567
Stick Systems	0.442
Point-Supported Glazing Systems (Spider System)	0.292

Table 4.19: Descending order of the durability utility scores

Curtain Wall Alternative	Utility Score (U)
Precast Concrete Cladding Panels	0.808
Unitized Systems	0.600
Column-Cover and Spandrel Systems	0.542
Stick Systems	0.500
Unit-and-Mullion Systems	0.500
Point-Supported Glazing Systems (Spider System)	0.483

4.5 Model Implementation

The implementation of the developed MCDM model was carried out using the calculated mean of criteria weights and utility scores presented in Table 4.6 as well as Table 4.11 to Table 4.16, respectively. The model was implemented to evaluate each system independently. The highest value obtained from the model is the best alternative to be selected. Tables 4.20 to 4.25 indicate the implementation of the model for each curtain wall system. It is obvious that the terms of criteria weights, their prioritization, is the same for all systems. The terms of the utility scores varies from a system to another due to the variability of their performances with respect to different criteria. The obtained results from the model were ranked from the highest to the lowest value and then summarized in Table 4.26. It was found that the precast concrete cladding panels were the best system to be used in office buildings located in the Eastern Province of Saudi Arabia. The unitized systems obtained the second rank after the precast concrete cladding panels. Point-supported glazing systems (spider system) obtained the last rank.

Table 4.20: Evaluation of stick systems

Category	Criteria	Evaluation of Stick Systems		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.442	0.041
	Material Weight (C_2)	0.025	0.567	0.014
	Fire Resistance (C_3)	0.103	0.367	0.038
	Thermal Performance (C_4)	0.057	0.458	0.026
	Acoustical Performance (C_5)	0.040	0.500	0.020
	Water Tightness (C_6)	0.053	0.533	0.028
	Air Tightness (C_7)	0.045	0.558	0.025
	Simplicity of Design Details (C_8)	0.032	0.608	0.019
Economic Criteria	Erection Time (C_9)	0.031	0.492	0.015
	Ease of Construction (C_{10})	0.031	0.517	0.016
	Initial Cost (C_{11})	0.049	0.558	0.027
	Maintenance Cost (C_{12})	0.051	0.542	0.028
	Durability (expected service life) (C_{13})	0.075	0.500	0.038
	Maintainability (C_{14})	0.059	0.517	0.031
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.742	0.045
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.708	0.017
	Control of Light (C_{17})	0.030	0.617	0.019
	Safety During and after Construction (C_{18})	0.047	0.533	0.025
	Disturbance of Community During Construction (C_{19})	0.016	0.533	0.009
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.500	0.009
	Consumption of Materials (C_{21})	0.020	0.558	0.011
	Waste Generation (C_{22})	0.018	0.467	0.008
	Reusability/Recyclability of materials (C_{23})	0.023	0.500	0.012
	Total ($\sum W_n U_n$)			0.519

Table 4.21: Evaluation of unitized systems

Category	Criteria	Evaluation of Unitized Systems		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.575	0.053
	Material Weight (C_2)	0.025	0.567	0.014
	Fire Resistance (C_3)	0.103	0.483	0.050
	Thermal Performance (C_4)	0.057	0.633	0.036
	Acoustical Performance (C_5)	0.040	0.592	0.024
	Water Tightness (C_6)	0.053	0.600	0.032
	Air Tightness (C_7)	0.045	0.675	0.030
	Simplicity of Design Details (C_8)	0.032	0.533	0.017
Economic Criteria	Erection Time (C_9)	0.031	0.692	0.021
	Ease of Construction (C_{10})	0.031	0.575	0.018
	Initial Cost (C_{11})	0.049	0.525	0.026
	Maintenance Cost (C_{12})	0.051	0.458	0.023
	Durability (expected service life) (C_{13})	0.075	0.600	0.045
	Maintainability (C_{14})	0.059	0.492	0.029
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.658	0.039
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.642	0.015
	Control of Light (C_{17})	0.030	0.608	0.018
	Safety During and after Construction (C_{18})	0.047	0.567	0.027
	Disturbance of Community During Construction (C_{19})	0.016	0.650	0.010
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.542	0.010
	Consumption of Materials (C_{21})	0.020	0.567	0.011
	Waste Generation (C_{22})	0.018	0.592	0.011
	Reusability/Recyclability of materials (C_{23})	0.023	0.442	0.010
	Total ($\sum W_n U_n$)			0.570

Table 4.22: Evaluation of unit-and-mullion systems

Category	Criteria	Evaluation of Unit-and-Mullion Systems		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.583	0.054
	Material Weight (C_2)	0.025	0.533	0.013
	Fire Resistance (C_3)	0.103	0.442	0.046
	Thermal Performance (C_4)	0.057	0.575	0.033
	Acoustical Performance (C_5)	0.040	0.567	0.023
	Water Tightness (C_6)	0.053	0.600	0.032
	Air Tightness (C_7)	0.045	0.658	0.030
	Simplicity of Design Details (C_8)	0.032	0.475	0.015
Economic Criteria	Erection Time (C_9)	0.031	0.533	0.017
	Ease of Construction (C_{10})	0.031	0.550	0.017
	Initial Cost (C_{11})	0.049	0.483	0.024
	Maintenance Cost (C_{12})	0.051	0.433	0.022
	Durability (expected service life) (C_{13})	0.075	0.500	0.038
	Maintainability (C_{14})	0.059	0.467	0.028
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.608	0.036
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.633	0.015
	Control of Light (C_{17})	0.030	0.583	0.017
	Safety During and after Construction (C_{18})	0.047	0.575	0.027
	Disturbance of Community During Construction (C_{19})	0.016	0.600	0.010
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.483	0.009
	Consumption of Materials (C_{21})	0.020	0.533	0.011
	Waste Generation (C_{22})	0.018	0.508	0.009
	Reusability/Recyclability of materials (C_{23})	0.023	0.450	0.010
	Total ($\sum W_n U_n$)			0.534

Table 4.23: Evaluation of column-cover and spandrel systems

Category	Criteria	Evaluation of Column-Cover and Spandrel Systems		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.567	0.0520
	Material Weight (C_2)	0.025	0.508	0.013
	Fire Resistance (C_3)	0.103	0.458	0.047
	Thermal Performance (C_4)	0.057	0.542	0.031
	Acoustical Performance (C_5)	0.040	0.542	0.022
	Water Tightness (C_6)	0.053	0.583	0.031
	Air Tightness (C_7)	0.045	0.608	0.027
	Simplicity of Design Details (C_8)	0.032	0.575	0.018
Economic Criteria	Erection Time (C_9)	0.031	0.633	0.020
	Ease of Construction (C_{10})	0.031	0.608	0.019
	Initial Cost (C_{11})	0.049	0.550	0.027
	Maintenance Cost (C_{12})	0.051	0.492	0.025
	Durability (expected service life) (C_{13})	0.075	0.542	0.041
	Maintainability (C_{14})	0.059	0.492	0.029
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.592	0.036
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.650	0.016
	Control of Light (C_{17})	0.030	0.650	0.020
	Safety During and after Construction (C_{18})	0.047	0.550	0.026
	Disturbance of Community During Construction (C_{19})	0.016	0.633	0.010
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.575	0.010
	Consumption of Materials (C_{21})	0.020	0.567	0.011
	Waste Generation (C_{22})	0.018	0.467	0.008
	Reusability/Recyclability of materials (C_{23})	0.023	0.392	0.009
	Total ($\sum W_n U_n$)			0.547

Table 4.24: Evaluation of point-supported glazing systems (Spider System)

Category	Criteria	Evaluation of Point-Supported Glazing Systems (Spider System)		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.292	0.027
	Material Weight (C_2)	0.025	0.583	0.015
	Fire Resistance (C_3)	0.103	0.267	0.028
	Thermal Performance (C_4)	0.057	0.367	0.021
	Acoustical Performance (C_5)	0.040	0.358	0.014
	Water Tightness (C_6)	0.053	0.458	0.024
	Air Tightness (C_7)	0.045	0.442	0.020
	Simplicity of Design Details (C_8)	0.032	0.625	0.020
Economic Criteria	Erection Time (C_9)	0.031	0.642	0.020
	Ease of Construction (C_{10})	0.031	0.667	0.021
	Initial Cost (C_{11})	0.049	0.608	0.030
	Maintenance Cost (C_{12})	0.051	0.508	0.026
	Durability (expected service life) (C_{13})	0.075	0.483	0.036
	Maintainability (C_{14})	0.059	0.517	0.031
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.692	0.042
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.842	0.020
	Control of Light (C_{17})	0.030	0.500	0.015
	Safety During and after Construction (C_{18})	0.047	0.400	0.019
	Disturbance of Community During Construction (C_{19})	0.016	0.575	0.009
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.575	0.010
	Consumption of Materials (C_{21})	0.020	0.600	0.012
	Waste Generation (C_{22})	0.018	0.550	0.010
	Reusability/Recyclability of materials (C_{23})	0.023	0.433	0.010
	Total ($\sum W_n U_n$)			0.478

Table 4.25: Evaluation of precast concrete cladding panels

Category	Criteria	Evaluation of Precast Concrete Cladding Panels		
		Criteria Weight (W_n)	Utility Score (U_n)	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	0.642	0.059
	Material Weight (C_2)	0.025	0.292	0.007
	Fire Resistance (C_3)	0.103	0.708	0.073
	Thermal Performance (C_4)	0.057	0.667	0.038
	Acoustical Performance (C_5)	0.040	0.658	0.026
	Water Tightness (C_6)	0.053	0.667	0.035
	Air Tightness (C_7)	0.045	0.700	0.032
	Simplicity of Design Details (C_8)	0.032	0.575	0.018
Economic Criteria	Erection Time (C_9)	0.031	0.658	0.020
	Ease of Construction (C_{10})	0.031	0.608	0.019
	Initial Cost (C_{11})	0.049	0.525	0.026
	Maintenance Cost (C_{12})	0.051	0.558	0.028
	Durability (expected service life) (C_{13})	0.075	0.808	0.061
	Maintainability (C_{14})	0.059	0.558	0.033
	Availability of Materials from Local Suppliers (C_{15})	0.060	0.733	0.044
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	0.558	0.013
	Control of Light (C_{17})	0.030	0.492	0.015
	Safety During and after Construction (C_{18})	0.047	0.558	0.026
	Disturbance of Community During Construction (C_{19})	0.016	0.542	0.009
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	0.458	0.008
	Consumption of Materials (C_{21})	0.020	0.550	0.011
	Waste Generation (C_{22})	0.018	0.617	0.011
	Reusability/Recyclability of materials (C_{23})	0.023	0.300	0.007
	Total ($\sum W_n U_n$)			0.620

Table 4.26: Summary of the evaluation of curtain wall alternatives

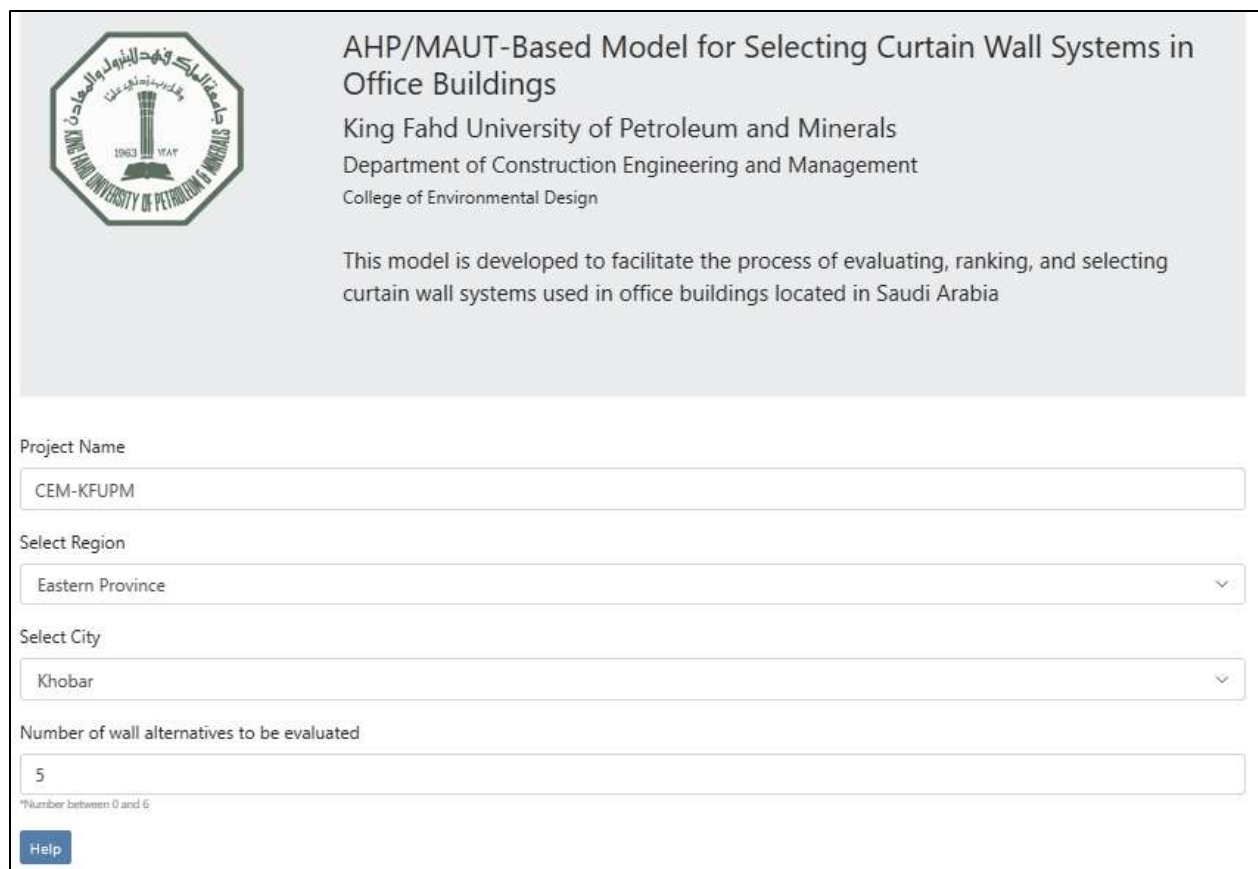
Curtain Wall Alternative	Total ($\sum W_n U_n$)	Rank
Precast Concrete Cladding Panels	0.620	1
Unitized Systems	0.570	2
Column-Cover and Spandrel Systems	0.547	3
Unit-and-Mullion Systems	0.534	4
Stick Systems	0.519	5
Point-Supported Glazing Systems (Spider System)	0.478	6

4.6 Computer Implementation

4.6.1. Overview of the Computer Application

The computer implementation of the developed MCDM model is an essential step that illustrates the model use by practitioners during the early design stages of office buildings. Angular web framework was used for developing the computer application and then it was deployed through the use of Angular's localhost server. The design of the user interface considered different inputs from users which are the project information, numbers and names of the alternatives, and the evaluation of the alternatives with respect to all of the 23 criteria. Appendix I shows the view code application. Figure 4.9 shows the first part of the application. Firstly, the name of the project is typed the user. Then the user selects the project region. Accordingly, the cities located in the selected region appear in the next box. After that the user enters the number of alternatives to be evaluated. According to that number, similar number of boxes appear for providing the names of wall systems to be evaluated. The application allows users to enter the name of the system that is not available in the database. This provides an advantage to designers who are dealing with new curtain wall systems in the local market. The user then can click on the help option in order to get

background of the scale to be used in the evaluation process as illustrated in Figure 4.10. After that the designer is able to evaluate the wall alternatives with respect to all of the technical, economic, and socio-environmental criteria as in figures 4.11, 4.12, and 4.13 respectively. The results are then provided to the user at which the total scores of alternatives can be sorted from the highest to the lowest values, as shown in Figure 4.14. The independent evaluation for each wall alternative is based on a multiplication of criteria weights, (the mean of the global weight obtained from the 14 consisted responses), that are saved in the application's local storage by their associated utility scores. When the user assigns a score of 1, the not preferred option that has a utility score of 0.00, the total scores for all alternatives are zero as indicated in figures 4.11 to 4.14.



The screenshot displays the user interface for the 'AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings'. At the top left is the logo of King Fahd University of Petroleum & Minerals (KFUPM). The header text identifies the institution as 'King Fahd University of Petroleum and Minerals', the 'Department of Construction Engineering and Management', and the 'College of Environmental Design'. A descriptive paragraph states: 'This model is developed to facilitate the process of evaluating, ranking, and selecting curtain wall systems used in office buildings located in Saudi Arabia'.

The main form area contains the following input fields:

- Project Name:** A text input field containing 'CEM-KFUPM'.
- Select Region:** A dropdown menu with 'Eastern Province' selected.
- Select City:** A dropdown menu with 'Khobar' selected.
- Number of wall alternatives to be evaluated:** A text input field containing '5'. Below this field is a small note: '*Number between 0 and 6'.

A blue 'Help' button is located at the bottom left of the form area.

Figure 4.9: Entry of project information



AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings

King Fahd University of Petroleum and Minerals
Department of Construction Engineering and Management
College of Engineering

This model is designed to help you in evaluating, ranking, and selecting curtain wall systems based on different criteria in Saudi Arabia

Project Name

CEM-KFUPM

Select Region

Eastern Province

Select City

Khobar

Number of wall alternatives to be evaluated

5

*Number: between 0 and 6

Help

Kindly use the scale that ranges from 1 to 5 in the following table to evaluate the selected curtain wall systems based on different criteria

Input	Description
1	Not Preferred
2	Preferred Somewhat
3	Moderately Preferred
4	Very Preferred
5	Extremely Preferred

Figure 4.10: Description of the evaluation scale

Criteria / Wall Alternatives	Stick System ▾	Unitized Sysl ▾	Point-Suppo ▾	Precast Conc ▾	Other ▾ New System
	Technical Criteria				
Wind Resistance	1	1	1	1	1
Material Weight	1	1	1	1	1
Fire Resistance	1	1	1	1	1
Thermal Performance	1	1	1	1	1
Acoustical Performance	1	1	1	1	1
Water Tightness	1	1	1	1	1
Air Tightness	1	1	1	1	1
Simplicity of Design Details	1	1	1	1	1

Figure 4.11: Evaluation of selected alternatives with respect to technical criteria

Economic Criteria					
Erection Time	1	1	1	1	1
Ease of Construction	1	1	1	1	1
Initial Cost	1	1	1	1	1
Maintenance Cost	1	1	1	1	1
Durability (expected service life)	1	1	1	1	1
Maintainability	1	1	1	1	1
Availability of Materials from Local Suppliers	1	1	1	1	1

Figure 4.12: Evaluation of selected alternatives with respect to economic criteria

Socio-environmental Criteria					
Aesthetics	1	1	1	1	1
Control of Light	1	1	1	1	1
Safety During and after Construction	1	1	1	1	1
Disturbance of Community During Construction	1	1	1	1	1
Energy Consumption through Required Construction Equipment	1	1	1	1	1
Consumption of Materials	1	1	1	1	1
Waste Generation	1	1	1	1	1
Reusability/Recyclability of materials	1	1	1	1	1

Show Results

Figure 4.13: Evaluation of selected alternatives with respect to socio-environmental criteria

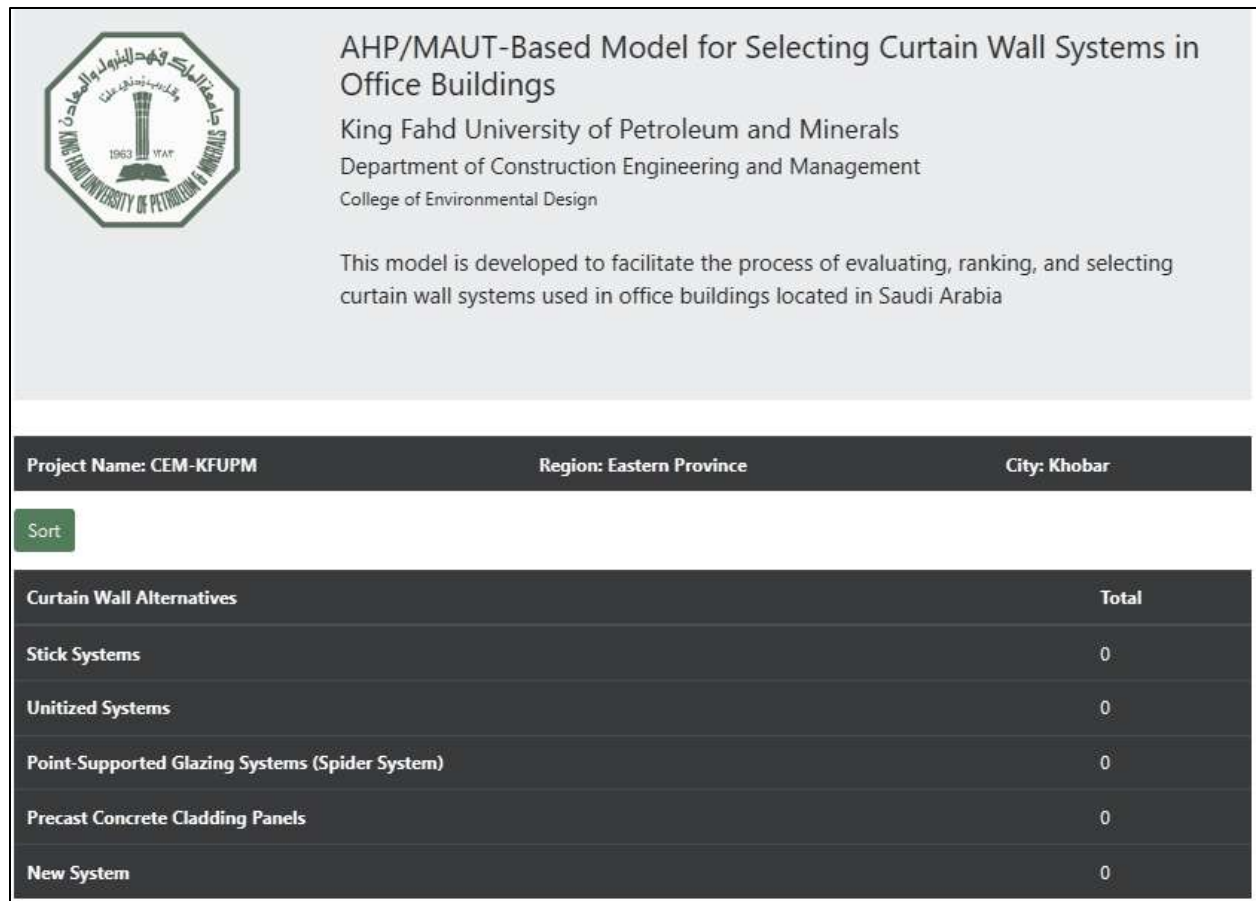


Figure 4.14: Total scores of alternatives based on the user's evaluation

4.6.2. Validation Results

A structured interviews' form was designed for validating the model with local experts. The form consisted of four parts which include filling general information of interviewees, selecting curtain wall systems that can be considered in office building projects, evaluating selected alternatives with respect to all criteria, identifying the most preferred alternative by experts, and entering the evaluation data to the computer application. Appendix J shows the form used in the interviews. In this study, two interviews were conducted, and their results of both cases are as the following:

4.6.2.1 Case 1

The first interviewee considered two systems that can be used in an office building located in Khobar. The selected alternatives are the stick system and the unitized systems. Both systems were evaluated in the form. The stick system was preferred over the unitized for different reasons based on the interviewee's experience. The recoded reasons from the interview are "safer at erection compared to other systems", "lighter weight", "less needed equipment", "lower cost compared to other systems", and "easier to maintain and repair". Then the evaluation of the alternatives was entered to the computer application and then the alternatives were evaluated as shown in Figure 4.15 to Figure 4.18. The results of implementing the model on the entered data were in agreement with the interviewee judgement. Tables 4.27 and 4.28 illustrates the manual evaluation which is similar to the computer application output. The rank of the interviewee's evaluation and judgment was different from the survey's output. Accordingly, the output of the questionnaire survey was shared with interviewee in order to obtain a feedback of that. The interviewee mentioned that in accordance with the point of view of the filed work, most of the work associated with the unitized system is generally carried out by the supplier. Hence, it generally can provide an advantage to the installation team since there is more liability on the supplier. However, unitized system might require, depending on the nature of the project, more detailed coordination between the site team and the planning department at which the site condition is required to be studied carefully. Furthermore, some designers give lower priorities to the detailed work and coordination to be carried out in the job site. Moreover, the score of any curtain wall system, either stick or unitized, could vary depending on the nature of the project, (e.g, detailed design of the building and its height and also the surrounding environment), which indicates that assigned score of the system varies based on different experiences and point of views.

Criteria / Wall Alternatives	Stick Systems	Unitized Systems
Technical Criteria		
Wind Resistance	3	3
Material Weight	4	2
Fire Resistance	3	4
Thermal Performance	3	4
Acoustical Performance	3	4
Water Tightness	3	3
Air Tightness	3	3
Simplicity of Design Details	4	5

Figure 4.15: Evaluation of selected alternatives with respect to technical criteria by the first interviewee

Economic Criteria		
Erection Time	3	5
Ease of Construction	3	4
Initial Cost	4	2
Maintenance Cost	4	2
Durability (expected service life)	3	3
Maintainability	3	2
Availability of Materials from Local Suppliers	5	2

Figure 4.16: Evaluation of selected alternatives with respect to economic criteria by the first interviewee

Socio-environmental Criteria		
Aesthetics	4	4
Control of Light	3	3
Safety During and after Construction	4	2
Disturbance of Community During Construction	4	5
Energy Consumption through Required Construction Equipment	3	2
Consumption of Materials	4	3
Waste Generation	3	4
Reusability/Recyclability of materials	3	2

[Show Results](#)

Figure 4.17: Evaluation of selected alternatives with respect to socio-environmental criteria by the first interviewee



AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings

King Fahd University of Petroleum and Minerals
Department of Construction Engineering and Management
College of Environmental Design

This model is developed to facilitate the process of evaluating, ranking, and selecting curtain wall systems used in office buildings located in Saudi Arabia

Project Name: Case 1
Region: Eastern Province
City: Khobar

Sort

Curtain Wall Alternatives	Total
Stick Systems	0.5954999999999999
Unitized Systems	0.52425

Figure 4.18: Total scores of alternatives based on the first interviewee's evaluation

Table 4.27: Evaluation of the stick system by the first interviewee

Category	Criteria	Evaluation of the Stick System			
		Criteria Weight (W_n)	Assigned Score	U_n	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	3	0.50	0.046
	Material Weight (C_2)	0.025	4	0.75	0.019
	Fire Resistance (C_3)	0.103	3	0.50	0.052
	Thermal Performance (C_4)	0.057	3	0.50	0.029
	Acoustical Performance (C_5)	0.040	3	0.50	0.020
	Water Tightness (C_6)	0.053	3	0.50	0.027
	Air Tightness (C_7)	0.045	3	0.50	0.023
	Simplicity of Design Details (C_8)	0.032	4	0.75	0.024
Economic Criteria	Erection Time (C_9)	0.031	3	0.50	0.016
	Ease of Construction (C_{10})	0.031	3	0.50	0.016
	Initial Cost (C_{11})	0.049	4	0.75	0.037
	Maintenance Cost (C_{12})	0.051	4	0.75	0.038
	Durability (expected service life) (C_{13})	0.075	3	0.50	0.038
	Maintainability (C_{14})	0.059	3	0.50	0.030
	Availability of Materials from Local Suppliers (C_{15})	0.060	5	1.00	0.060
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	4	0.75	0.018
	Control of Light (C_{17})	0.030	3	0.50	0.015
	Safety During and after Construction (C_{18})	0.047	4	0.75	0.035
	Disturbance of Community During Construction (C_{19})	0.016	4	0.75	0.012
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	3	0.50	0.009
	Consumption of Materials (C_{21})	0.020	4	0.75	0.015
	Waste Generation (C_{22})	0.018	3	0.50	0.009
	Reusability/Recyclability of materials (C_{23})	0.023	3	0.50	0.012
Total ($\sum W_n U_n$)					0.596

Table 4.28: Evaluation of the unitized system by the first interviewee

Category	Criteria	Evaluation of the Unitized System			
		Criteria Weight (W_n)	Assigned Score	U_n	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	3	0.50	0.046
	Material Weight (C_2)	0.025	2	0.25	0.006
	Fire Resistance (C_3)	0.103	4	0.75	0.077
	Thermal Performance (C_4)	0.057	4	0.75	0.043
	Acoustical Performance (C_5)	0.040	4	0.75	0.030
	Water Tightness (C_6)	0.053	3	0.50	0.027
	Air Tightness (C_7)	0.045	3	0.50	0.023
	Simplicity of Design Details (C_8)	0.032	5	1.00	0.032
Economic Criteria	Erection Time (C_9)	0.031	5	1.00	0.031
	Ease of Construction (C_{10})	0.031	4	0.75	0.023
	Initial Cost (C_{11})	0.049	2	0.25	0.012
	Maintenance Cost (C_{12})	0.051	2	0.25	0.013
	Durability (expected service life) (C_{13})	0.075	3	0.50	0.038
	Maintainability (C_{14})	0.059	2	0.25	0.015
	Availability of Materials from Local Suppliers (C_{15})	0.060	2	0.25	0.015
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	4	0.75	0.018
	Control of Light (C_{17})	0.030	3	0.50	0.015
	Safety During and after Construction (C_{18})	0.047	2	0.25	0.012
	Disturbance of Community During Construction (C_{19})	0.016	5	1.00	0.016
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	2	0.25	0.005
	Consumption of Materials (C_{21})	0.020	3	0.50	0.010
	Waste Generation (C_{22})	0.018	4	0.75	0.014
	Reusability/Recyclability of materials (C_{23})	0.023	2	0.25	0.006
Total ($\sum W_n U_n$)					0.524

4.6.2.2 Case 2

The second interviewee considered two systems to be used in an office building project located in Khobar. The selected alternatives are the stick system and the precast concrete cladding panels. The two systems were evaluated by the interviewee in the form. The stick system was preferred over the precast concrete cladding panels. The stated reasons of this judgement by the interviewee are “might have lower cost”, “easy to maintain”, “provided by many suppliers”, “lower cost compared to other systems”, and “easy to install”. Then the evaluation of the alternatives was entered to the computer application and then the alternatives were evaluated as shown in Figure 4.19 to Figure 4.22. The results of implementing the model on the entered data were not in agreement with the interviewee judgement. Tables 4.29 and 4.30 illustrates the manual evaluation which is similar to the computer application output. The rank of the interviewee’s evaluation and judgment was similar to the survey’s output. The prioritization of criteria used in the model was shared with the expert in order to get feedback about the results. It was mentioned that some local designers are more aware of the criteria related to construction phase (e.g. cost, easiness, requirement of equipment, and availability) than other performance aspects of wall alternatives which might be related to important technical, economic, and socio-environmental criteria. Accordingly, it is obvious that the prioritization of criteria can vary from one practitioner to another. However, having such consistent prioritization of criteria can provide a comprehensive checklist for decision-makers during early design stages that facilitates considering different essential criteria for the construction and operation phases of buildings. This can enhance the decision-making process and minimize the subjectivity of the practitioner.

Criteria / Wall Alternatives	Stick Systems	Precast Concrete Cladding Panel
Technical Criteria		
Wind Resistance	4	4
Material Weight	5	2
Fire Resistance	2	5
Thermal Performance	3	4
Acoustical Performance	3	5
Water Tightness	3	4
Air Tightness	3	4
Simplicity of Design Details	5	4

Figure 4.19: Evaluation of selected alternatives with respect to technical criteria by the second interviewee

Economic Criteria		
Erection Time	2	4
Ease of Construction	5	2
Initial Cost	4	4
Maintenance Cost	3	4
Durability (expected service life)	4	5
Maintainability	4	4
Availability of Materials from Local Suppliers	4	5

Figure 4.20: Evaluation of selected alternatives with respect to economic criteria by the second interviewee

Socio-environmental Criteria		
Aesthetics	5	3
Control of Light	3	3
Safety During and after Construction	5	2
Disturbance of Community During Construction	5	2
Energy Consumption through Required Construction Equipment	4	2
Consumption of Materials	4	2
Waste Generation	4	2
Reusability/Recyclability of materials	4	2

[Show Results](#)

Figure 4.21: Evaluation of selected alternatives with respect to socio-environmental criteria by the second interviewee



AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings
 King Fahd University of Petroleum and Minerals
 Department of Construction Engineering and Management
 College of Environmental Design

This model is developed to facilitate the process of evaluating, ranking, and selecting curtain wall systems used in office buildings located in Saudi Arabia

Project Name: Case 2 Region: Eastern Province City: Khobar

[Sort](#)

Curtain Wall Alternatives	Total
Precast Concrete Cladding Panels	0.70625
Stick Systems	0.6569999999999999

Figure 4.22: Total scores of alternatives based on the second interviewee's evaluation

Table 4.29: Evaluation of the stick system by the second interviewee

Category	Criteria	Evaluation of the Stick System			
		Criteria Weight (W_n)	Assigned Score	U_n	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	4	0.75	0.069
	Material Weight (C_2)	0.025	5	1.00	0.025
	Fire Resistance (C_3)	0.103	2	0.25	0.026
	Thermal Performance (C_4)	0.057	3	0.50	0.029
	Acoustical Performance (C_5)	0.040	3	0.50	0.020
	Water Tightness (C_6)	0.053	3	0.50	0.027
	Air Tightness (C_7)	0.045	3	0.50	0.023
	Simplicity of Design Details (C_8)	0.032	5	1.00	0.032
Economic Criteria	Erection Time (C_9)	0.031	2	0.25	0.008
	Ease of Construction (C_{10})	0.031	5	1.00	0.031
	Initial Cost (C_{11})	0.049	4	0.75	0.037
	Maintenance Cost (C_{12})	0.051	3	0.50	0.026
	Durability (expected service life) (C_{13})	0.075	4	0.75	0.056
	Maintainability (C_{14})	0.059	4	0.75	0.044
	Availability of Materials from Local Suppliers (C_{15})	0.060	4	0.75	0.045
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	5	1.00	0.024
	Control of Light (C_{17})	0.030	3	0.50	0.015
	Safety During and after Construction (C_{18})	0.047	5	1.00	0.047
	Disturbance of Community During Construction (C_{19})	0.016	5	1.00	0.016
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	4	0.75	0.014
	Consumption of Materials (C_{21})	0.020	4	0.75	0.015
	Waste Generation (C_{22})	0.018	4	0.75	0.014
	Reusability/Recyclability of materials (C_{23})	0.023	4	0.75	0.017
Total ($\sum W_n U_n$)					0.657

Table 4.30: Evaluation of the precast cladding panels by the second interviewee

Category	Criteria	Evaluation of the Precast Cladding Panels			
		Criteria Weight (W_n)	Assigned Score	U_n	$W_n \times U_n$
Technical Criteria	Wind Resistance (C_1)	0.092	4	0.75	0.069
	Material Weight (C_2)	0.025	2	0.25	0.006
	Fire Resistance (C_3)	0.103	5	1.00	0.103
	Thermal Performance (C_4)	0.057	4	0.75	0.043
	Acoustical Performance (C_5)	0.040	5	1.00	0.040
	Water Tightness (C_6)	0.053	4	0.75	0.040
	Air Tightness (C_7)	0.045	4	0.75	0.034
	Simplicity of Design Details (C_8)	0.032	4	0.75	0.024
Economic Criteria	Erection Time (C_9)	0.031	4	0.75	0.023
	Ease of Construction (C_{10})	0.031	2	0.25	0.008
	Initial Cost (C_{11})	0.049	4	0.75	0.037
	Maintenance Cost (C_{12})	0.051	4	0.75	0.038
	Durability (expected service life) (C_{13})	0.075	5	1.00	0.075
	Maintainability (C_{14})	0.059	4	0.75	0.044
	Availability of Materials from Local Suppliers (C_{15})	0.060	5	1.00	0.060
Socio-Environmental Criteria	Aesthetics (C_{16})	0.024	3	0.50	0.012
	Control of Light (C_{17})	0.030	3	0.50	0.015
	Safety During and after Construction (C_{18})	0.047	2	0.25	0.012
	Disturbance of Community During Construction (C_{19})	0.016	2	0.25	0.004
	Energy Consumption through Required Construction Equipment (C_{20})	0.018	2	0.25	0.005
	Consumption of Materials (C_{21})	0.020	2	0.25	0.005
	Waste Generation (C_{22})	0.018	2	0.25	0.005
	Reusability/Recyclability of materials (C_{23})	0.023	2	0.25	0.006
Total ($\sum W_n U_n$)					0.706

4.7 Summary

This chapter provided and discussed the results obtained from each step of the research methodology, which contribute to achieve the research objectives. Based on a comprehensive literature review and semi-structured interviews conducted with five local experts working in design offices, it was found that the stick systems, unitized systems, unit-and-mullion systems, column-cover-and spandrel systems, point-supported glazing systems, and precast concrete cladding panels were the most common systems used in office buildings located in the Eastern Province. Furthermore, there were some criteria removed and there were no additional criteria identified from local experts. A preliminary questionnaire survey was designed and used as a pilot survey that was sent to a total of five experts in design offices and consulting firms, prior its distribution to the targeted sample. The conducted pilot study resulted in modifications in some terminologies of criteria and curtain wall systems as well as division or combination of some criteria. The finalized design of structural hierarchy in this study consists of a total of 23 criteria categorized into three main groups. Based on collecting responses from representatives of engineering and design consulting firms in the Eastern Province of Saudi Arabia, it was found that the fire resistance scored the highest weight among other criteria. The survey's results revealed that the precast concrete cladding panels were the best system to be used in office buildings located in the Eastern Province of Saudi Arabia. Angular web framework was used for developing a computer application and then it was deployed through the use of Angular's localhost server. The model validation with experts indicated that the score of any curtain wall system could vary depending on the nature of the project. In addition, some local designers are more aware of the criteria related to construction phase than other performance aspects of wall alternatives. The prioritization of criteria can vary from one practitioner to another.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a summary of the study including the research objectives and research methodology designed to achieve the objectives. In addition, the findings, conclusion, and recommendations are presented in this chapter.

5.2 Summary of the Study

The selection of curtain walls plays a vital role in technical, economic, and socio-environmental aspects in office buildings. Furthermore, there are many alternatives of them which can be used in those buildings. Their selection process requires the evaluation of various criteria which makes the selection of the most appropriate wall type a challenging task for decision-makers. Interviews with representatives of engineering and architectural design firms in the Eastern Province of Saudi Arabia were conducted to investigate the current practices adopted by local practitioners for selecting curtain wall systems in Saudi Arabia. The interviews revealed that the selection of the curtain wall is relied on the experience of the designers rather than based on a systematic approach. Furthermore, it was found that there is no available tool that can be used to assist in the selection process.

This research aims to develop a model that facilitates the selection processes of curtain wall systems utilized in office buildings in the Eastern Province of Saudi Arabia. Accordingly, three objectives were formulated. The first objective is to identify most common alternatives of curtain

wall systems utilized in office buildings and their selection criteria. Secondly, a development of an MCDM mode was considered for facilitating the process of evaluating, ranking, and selecting curtain wall systems utilized in office buildings. The final objective is to implement the developed MCDM model in a prototype computer application.

The research methodology of this study was designed to achieve the objectives. A set of eight sequential steps pertaining to that achievement were followed in this study. Two steps, namely literature review and interviews with local experts, contributed for achieving the first objective. The second objective was achieved by five steps. Those steps are the design of questionnaire survey, pilot-testing of the questionnaire, data collection, data analysis, and development and implementation of the MCDM model. The last step contributed in achieving the last objective.

5.3 Findings

The main findings of this research are summarized as the following:

- Based on a comprehensive review of literature, semi-structured interviews with local experts, and pilot study, a total of 23 criteria was found to have an influence in the selection process of curtain wall systems. The criteria were categorized into three main categories, namely technical, economic, and socio-environmental criteria. Total of six curtain walls were identified to be the most common ones used in office buildings.
- A questionnaire survey consisting of two main sections, AHP and MAUT, was distributed to professionals working in design offices and consulting firms who were involved in the design and selection of curtain wall systems. The results revealed that the fire resistance obtained the highest weight among the other technical criteria and it also has the highest weight among all weights of criteria.

- The results of the questionnaire indicated that that the precast concrete cladding panels were the best system to be used in office buildings located in the Eastern Province of Saudi Arabia.
- Angular web framework was used for developing a computer application and then it was deployed through the use of Angular's localhost server. The model validation reveals that some designers give lower priorities to the detailed work and coordination to be carried out in the job site.
- The score of any curtain wall system could vary depending on the nature of the project, (e.g, detailed design of the building and its height and also the surrounding environment), which indicates that assigned score of the system varies based on different experiences and point of views.
- The validation also incited that some local designers are more aware of the criteria related to construction phase than other performance aspects of wall alternatives. The prioritization of criteria can vary from one practitioner to another.

5.4 Conclusion

Curtain walls are the external walls of buildings that don't carry loads, except their weight and wind loads. They are used in different types of buildings and the major use of them is in office buildings. The selection of curtain walls plays a vital role in different aspects of buildings which include construction safety, construction duration, construction and maintenance costs, and energy consumption. The literature shows that there are many alternatives of curtain walls that can be used in office buildings and the selection process requires the evaluation of quantitative and qualitative criteria which makes the selection of the most appropriate type of wall a challenging

task for decision-makers. An investigation to the current practices adopted by local practitioners for selecting curtain wall systems revealed that the selection of the curtain wall is relied on the experience of the designers rather than based on a systematic approach. Furthermore, it was found that there is no available tool that can be used to assist in the selection process. The subjectivity associated with the architectural considerations, such as the aesthetics and appearance of the system, has a significant impact on the selection process. The economic aspects also are one of the main considerations that influence the selection process. This can be related to the total cost of the system and its availability in the local market. In addition, the technical performance of the system has an impact on selecting a particular system. It was stated that having the right designer is a key factor for selecting the suitable curtain wall system.

This research aims to develop a model that facilitates the selection processes of curtain wall systems utilized in office buildings. The research objectives are to identify most common alternatives of curtain wall systems and their selection criteria, to develop an MCDM model for evaluating, ranking, and selecting curtain wall systems utilized in office buildings, and to implement the developed MCDM model in a prototype computer application. The achievement of those objectives was carried out through the research methodology. It was found that the fire resistance scored the highest weight among other criteria. The results revealed that the precast concrete cladding panels were the best system to be used in office buildings located in the Eastern Province of Saudi Arabia. The model validation with experts indicated that the score of any curtain wall system could vary depending on the nature of the project. In addition, some local designers are more aware of the criteria related to construction phase than other performance aspects of wall alternatives. The prioritization of criteria can vary from one practitioner to another. Having a consistent prioritization of criteria can provide a comprehensive checklist for decision-makers

during early design stages that facilitates considering different essential criteria for the construction and operation phases of buildings. This can enhance the decision-making process and minimize the subjectivity of the practitioner.

5.5 Recommendations

Based on the findings of this research, the following recommendations were formulated for promoting the adoption of the MCDM models by local practitioners when they are involved in the selection of curtain wall systems used in office buildings:

- Regardless the nature the project, decision-makers involved in the design and selection of curtain walls used in office buildings are encouraged to adopt the MCDM model in their practices. This can aid in providing a comprehensive checklist of criteria to practitioners to consider in the early design stages.
- Although some local designers are more aware of the criteria related to construction phase (e.g. cost, easiness, requirement of equipment, and availability) than other performance aspects of wall alternatives which might be related to important technical, economic, and socio-environmental criteria, those practitioners are encouraged to have proper consideration of both of the construction and operation phases of buildings which contributes to minimize the subjectivity during the decision-making process.
- Although the socio-environmental criteria obtained lower weights compared to the technical and economic criteria, it is essential to raise the awareness about considering such criteria during the early design stages which contribute to the adoption of sustainability and friendly environment concepts on buildings. The consideration of such sustainable criteria by positioners facilitates meeting the needs of the current and future generations.

- Although new technologies in the construction might become more popular, practitioners are encouraged to have a detailed analysis of the nature of the project (e.g, detailed design of the building and its height and also the surrounding environment), prior to evaluate any alternative to be used in the project. After performing such analysis, practitioners are advised to score the alternatives with respect to the project conditions rather than based on past experiences.
- It is recommended that for practitioners having different prioritization of criteria to consider similar a system, but it should consist of AHP matrices having consistency checker in order to develop their own prioritization.

5.6 Future Research

The model was developed for selecting curtain wall systems used for office buildings located in the Eastern Province of Saudi Arabia. Similar work should be considered by other researchers and practitioners in other regions in the Kingdom as well in other neighboring countries in the region. Future studies may include developing MCDM models for other building systems, such as dry wall partitions and ceilings.

References

- Abu Dabous, S., & Alkass, S. (2010). A multi-attribute ranking method for bridge management. *Engineering, Construction and Architectural Management*, 17(3), 282–291.
- Akadiri, P. O., Olomolaiye, P. O., & Chinyio, E. A. (2013). Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Automation in Construction*, 30, 113–125.
- Al-Hammad, A., & Hassanain, M. (1996). Value engineering in the assessment of exterior building wall systems. *Journal of Architectural Engineering*, 2(3), 115–119.
- Al-Hammad, A., Hassanain, M., & Juaim, M. N. (2014). Evaluation and selection of curtain wall systems for medium-high rise building construction. *Structural Survey*, 32(4), 299–314.
- Al-Mulla, E. A. (2018). Direction to all engineering and consultancy offices accredited by the Eastern Province Municipality regarding the role of engineering offices in the implementation of building code requirements. (In Arabic). Dammam: Eastern Province Municipality.
- Al-Mulla, E. A. (2019a). Direction to all engineering and consultancy offices accredited by the Eastern Province Municipality regarding the conformity of cladding products with specifications. (In Arabic). Dammam: Eastern Province Municipality.
- Al-Mulla, E. A. (2019b). Direction to all engineering and consultancy offices accredited by the Eastern Province Municipality regarding the use of Saber E-Platform to inspect products and issue conformity assessment certificates electronically. (In Arabic). Dammam: Eastern Province Municipality.
- Al-Rifai, J., & Amoudi, O. (2016). Understanding the key factors of construction waste in Jordan. *Jordan Journal of Civil Engineering*, Volume, 10(2), 244–253.
- Allen, E., & Iano, J. (2014). *Fundamentals of Building Construction - Materials and Methods* (6th ed.). John Wiley & Sons, Inc.
- Alshamrani, O., Alshibani, A., & Alogaili, M. (2018). Analytic hierarchy process & multi attribute utility theory based approach for the selection of lighting systems in residential buildings: A case study. *Buildings*, 8(6), 1–17.
- Alshamrani, O., Mujeebu, M. A., Ashraf, N., Al-ghonamy, A., & Aichouni, M. (2017). Selection of external wall material by LCC technique for Office-cum-commercial building in the Eastern Province of Saudi Arabia. *Journal of Architecture and Planning*, 29(2), 243–256.
- Alshamrani, O. S. (2016). Life cycle assessment of low-rise office building with different structure-envelope configurations. *Canadian Journal of Civil Engineering*, 43(3), 193–200.
- Asharqia Chamber. (2019). About Chamber. Retrieved November 12, 2019, from <https://www.chamber.org.sa/sites/English/AboutChamber/Pages/AbouttheChamber.aspx>

- Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J., & Sorenson, K. (2001). *Guidebook to Decision-Making Methods*.
- Brown, G. W. (2013). Chapter 6: Waterproofing Design of Curtain Walls. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 73–86). Reston, Virginia: American Society of Civil Engineers.
- Chen, C.-J., Juan, Y.-K., & Hsu, Y.-H. (2017). Developing a systematic approach to evaluate and predict building service life. *Journal of Civil Engineering and Management*, 23(7), 890–901.
- Chen, Y., Okudan, G. E., & Riley, D. R. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, 19(2), 235–244.
- Chew, M. Y. L., De Silva, N., & Tan, S. S. (2004). A neural network approach to assessing building façade maintainability in the tropics. *Construction Management and Economics*, 22(6), 581–594.
- Chew, M. Y. L., Tan, S. S., & Kang, K. H. (2004). A technical evaluation index for curtain wall and cladding facades. *Structural Survey*, 22(4), 210–227.
- Ching, F. D. K. (2014). *Building Construction Illustrated* (Fifth Edit). Hoboken, New Jersey: John Wiley & Sons.
- Ching, F. D. K., & Shapiro, I. M. (2014). *Green Building Illustrated* (First). New Jersey: John Wiley & Sons, Inc.
- Chudley, R., & Greeno, R. (2014). *Building Construction Handbook* (10th ed.). Routledge.
- CIRIA. (1983). *Buildability: An assessment*. London.
- Clift, C. D., & Bonnheim, N. (2013). Chapter 7: Design of Curtain Walls for Wind Load. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 87–104). Reston, Virginia: American Society of Civil Engineers.
- Clough, R. H., Sears, G. A., Sears, S. K., Segner, R. O., & Rounds, J. L. (2015). *Construction Contracting: A Practical Guide to Company Management* (8th ed.). Wiley.
- Dalalah, D., Al-Oqla, F., & Hayajneh, M. (2010). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of cranes. *Jordan Journal of Mechanical and Industrial Engineering*, 4(5), 567–578.
- Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E., & Edwards, D. J. (2018). Review of application of analytic hierarchy process (AHP) in construction. *International Journal of Construction Management*, 1–17.
- Davis, M. L., & Masten, S. J. (2014). *Principles of Environmental Engineering and Science* (3rd ed.). McGraw-Hill Education.
- Dell’Isola, A. J., & Kirk, S. J. (1981). *Life cycle costing for design professionals*. McGraw-Hill,

Inc.

Dictionary.com. (2020). mid-rise. Retrieved January 31, 2020, from <https://www.dictionary.com/browse/mid-rise>

Doczy, R., & AbdelRazig, Y. (2017). Green buildings case study analysis using AHP and MAUT in sustainability and costs. *Journal of Architectural Engineering*, 23(3), 1–11.

Doloi, H. (2008). Application of AHP in improving construction productivity from a management perspective. *Construction Management and Economics*, 26(8), 841–854.

Downs, J. C. (1980). *Principles of Real Estate Management 1980* (Twelfth Ed). Institute of Real Estate Management.

Dyer, J. S., Fishburn, P. C., Steuer, R. E., Wallenius, J., & Zionts, S. (1992). Multiple criteria decision making, multiattribute utility theory: The next ten years. *Science, Management*, 38(5), 645–654.

Erdogan, S. A., Šaparauskas, J., & Turskis, Z. (2017). Decision making in construction management: AHP and Expert Choice approach. *Procedia Engineering*, 172, 270–276.

Fellows, R., & Liu, A. (2015). *Research Methods for Construction* (4th ed.). John Wiley & Sons, Ltd.

Forbes, L. H., & Ahmed, S. M. (2011). *Modern Construction: Lean Project Delivery and Integrated Practices*. CRC Press.

Foster, S. T. (2017). *Managing Quality: Integrating Supply Chain* (6th ed.). Pearson Education Limited.

Gaynor, G. H. (2015). *Decisions: An Engineering and Management Perspective* (1st ed.). Wiley-IEEE Press.

General Authority for Statistics. (2018). Statistical Book 2018. Retrieved November 6, 2019, from <https://www.stats.gov.sa/en/annual-statistical-book>

Goodwin, P., & Wright, G. (2000). *Decision Analysis for Management Judgement* (Second Edi). John Wiley and Sons.

Hassanain, M., Assaf, S., Al-Hammad, A., & Al-Nehmi, A. (2015). A multi-criteria decision making model for outsourcing maintenance services. *Facilities*, 33(3/4), 229–244.

Hosseini, S. T., Arefi, S. L., Bitarafan, M., Abazarlou, S., & Zavadskas, E. K. (2016). Evaluation types of exterior walls to reconstruct Iran earthquake areas (Ahar Heris Varzeqan) by using AHP and fuzzy methods. *International Journal of Strategic Property Management*, 20(3), 328–340.

Hyde, R. (1995). Buildability as a design concept for architects: a case study of laboratory buildings. *Engineering, Construction and Architectural Management*, 2(1), 45–56.

International Code Council. (2018). *2018 International Building Code*. International Code

Council, Inc.

- Jansen, S. J. T. (2011). Chapter 5: The Multi-attribute Utility Method. In S. J. T. Jansen, H. C. C. H. Coolen, & R. Goetgeluk (Eds.), *The Measurement and Analysis of Housing Preference and Choice*. Springer.
- Kassem, M., Dawood, N., & Mitchell, D. (2012). A decision support system for the selection of curtain wall systems at the design development stage. *Construction Management and Economics*, 30, 1039–1053.
- Kassem, M., & Mitchell, D. (2015). Bridging the gap between selection decisions of facade systems at the early design phase: Issues, Challenges and solutions. *Journal of Facade Design and Engineering*, 3(2), 165–183.
- Kaya, İ., & Kahraman, C. (2014). A comparison of fuzzy multicriteria decision making methods for intelligent building assessment. *Journal of Civil Engineering and Management*, 20(1), 59–69.
- Kish, L. (1995). *Survey Sampling*. New York: John Wiley & Sons.
- KPC. (2014). Kifah Skeleton Products: Kifah Wall Cladding. Dammam: Kifah Precast Company.
- Kultermann, E., & Spence, W. P. (2016). *Construction Materials, Methods and Techniques* (4th ed.). Delmar Cengage Learning.
- Lam, P. T. I., Chan, A. P. C., Wong, F. K. W., & Wong, F. W. H. (2007). Constructability rankings of construction systems based on the Analytical Hierarchy Process. *Journal of Architectural Engineering*, 13(1), 36–43.
- Li, Z., Shen, G. Q., & Alshawi, M. (2014). Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. *Resources, Conservation and Recycling*, 91, 27–39.
- Lin, Y. H., Tsai, K. T., Lin, M. Der, & Yang, M. Der. (2016). Design optimization of office building envelope configurations for energy conservation. *Applied Energy*, 171, 336–346.
- Majumder, M. (2015). *Impact of Urbanization on Water Shortage in Face of Climatic Aberrations*. Springer.
- Marzouk, M. (2006). Utility theory model for equipment selection. *Construction Innovation*, 6(1), 21–32.
- Marzouk, M., & Moselhi, O. (2003). A decision support tool for construction bidding. *Construction Innovation*, 3(1), 111–124.
- Marzouk, Mohamed, & Abubakr, A. (2016). Decision support for tower crane selection with building information models and genetic algorithms. *Automation in Construction*, 61, 1–15.
- McFarquhar, D. G. (2013a). Chapter 3: Materials and configurations. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 8–32). Reston, Virginia: American Society of Civil

Engineers.

- McFarquhar, D. G. (2013b). Chapter 4: Testing Mockups and Field Inspection. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 33–55). Reston, Virginia: American Society of Civil Engineers.
- Memari, A. M. (2013a). Chapter 11: New developments in curtain wall and glazing systems. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 194–209). Reston, Virginia: American Society of Civil Engineers.
- Memari, A. M. (2013b). Chapter 8: Design of Curtain Walls for Earthquake-Induced Loads and Drifts. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 105–128). Reston, Virginia: American Society of Civil Engineers.
- Morris, F. A. (2013a). Chapter 1: Introduction. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 1–2). American Society of Civil Engineers.
- Morris, F. A. (2013b). Chapter 2: Definition and types of curtain walls. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 3–7). Reston, Virginia: American Society of Civil Engineers.
- Morris, F. A. (2013c). Chapter 5: Design of Curtain Walls for Energy Performance. In A. M. Memari (Ed.), *Curtain wall systems : a primer* (pp. 56–72). Reston, Virginia: American Society of Civil Engineers.
- Moussavi Nadoushani, Z. S., Akbarnezhad, A., Ferre Jornet, J., & Xiao, J. (2017). Multi-criteria selection of façade systems based on sustainability criteria. *Building and Environment*, 121, 67–78.
- Narayanan, R. S., & Beeby, A. W. (2001). *Introduction to Design for Civil Engineers*. Taylor & Francis Group.
- Neufert, E. (2019). *Architects' Data* (5th ed.). Wiley-Blackwell.
- NIDLP. (2017). *National Industrial Development and Logistics Program: Delivery Plan 2018-2020*. Saudi Vision 2030.
- NTP. (2018). *National Transformation Program: Delivery Plan 2018-2020*. Saudi Vision 2030.
- OECD. (2008). *Handbook of Constructing Composite Indicators: Methodology and user guide*. OECD.
- PMI. (2017). *A Guide to the Project Management Body of Knowledge* (6th ed.). Project Management Institute.
- Pratt, D. J. (2011). *Fundamentals of construction estimating* (3rd ed.). Delmar, Cengage Learning.
- Radhi, H. (2010). On the optimal selection of wall cladding system to reduce direct and indirect CO₂ emissions. *Energy*, 35, 1412–1424.

- Rapone, G., & Saro, O. (2012). Optimisation of curtain wall faades for office buildings by means of PSO algorithm. *Energy and Buildings*, 45, 189–196.
- Rios, F. C., Grau, D., & Chong, W. K. (2019). Reusing exterior wall framing systems: A cradle-to-cradle comparative life cycle assessment. *Waste Management*, 94, 120–135.
- Rosen, H., & Bennett, P. (1979). *Construction Materials Evaluation and Selection: A Systematic Approach*. John Wiley & Sons.
- Rumane, A. R. (2017). 1. Overview of Construction Projects. In A. R. Rumane (Ed.), *Handbook of Construction Management: Scope, Schedule, and Cost Control (Systems Innovation Book Series)* (pp. 1–11). CRC Press.
- Saaty, T. L., & Vargas, L. G. (1994). *Decision Making in Economics, Political, Social and Technological Environment with the Analytic Hierarchy Process*. Pittsburg: RWS Publications.
- Saud Building Code National Committee. (2018). *Saudi Building Code- General (SBC 201)*. Saud Building Code National Committee.
- Shapira, A., & Simcha, M. (2009). AHP-based weighting of factors affecting safety on construction sites with tower cranes. *Journal of Construction Engineering and Management*, 135(4), 307–318.
- Sherratt, F., & Farrell, P. (2015). *Introduction to Construction Management*. Routledge.
- Singhaputtangkul, N., Low, S. P., Teo, A. L., & Hwang, B.-G. (2014). Criteria for architects and engineers to achieve sustainability and buildability in building envelope designs. *Journal of Management in Engineering*, 30(2), 236–245.
- Song, Y. W., Park, J. C., Chung, M. H., Choi, B. Do, & Park, J. H. (2013). Thermal performance evaluation of curtain wall frame types. *Journal of Asian Architecture and Building Engineering*, 12(1), 157–163.
- Tam, C. M., Tam, V. W. Y., Chan, J. K. W., & Ng, W. C. Y. (2005). Use of prefabrication to minimize construction waste - A case study approach. *International Journal of Construction Management*, 5(1), 91–101.
- Tam, V. W. Y., Tam, C. M., Zeng, S. X., & Ng, W. C. Y. (2007). Towards adoption of prefabrication in construction. *Building and Environment*, 42(10), 3642–3654.
- Temiz, I., & Calis, G. (2017). Selection of construction equipment by using multi-criteria decision making methods. *Procedia Engineering*, 196, 286–293.
- Triantaphyllou, E. (2000). *Multi-Criteria Decision Making Methods: A Comparative Study*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Umar, U. A., Shafiq, N., Malakahmad, A., Nuruddin, M. F., & Khamidi, M. F. (2017). A review on adoption of novel techniques in construction waste management and policy. *Journal of Material Cycles and Waste Management*, 19(4), 1361–1373.

- Ünver, R., Akdağ, N. Y., Gedik, G. Z., Öztürk, L. D., & Karabiber, Z. (2004). Prediction of building envelope performance in the design stage: an application for office buildings. *Building and Environment*, 39, 143–152.
- Velasquez, M., & Hester, P. T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research*, 10(2), 56–66.
- Volf, M., Lupíšek, A., Bureš, M., Nováček, J., Hejtmánek, P., & Tywoniak, J. (2018). Application of building design strategies to create an environmentally friendly building envelope for nearly zero-energy buildings in the central European climate. *Energy and Buildings*, 165, 35–46.
- Wong, J. K. W., & Li, H. (2008). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment*, 43, 108–125.
- Wyon, D. P. (2004). The effects of indoor air quality on performance and productivity. *Indoor Air*, 14(7), 92–101.
- Yates, J. K., & Castro-Lacouture, D. (2016). *Sustainability in Engineering Design and Construction* (1st ed.). CRC Press.
- Zhang, S., Pan, W., & Kumaraswamy, M. (2014). A multi-criteria decision framework for the selection of low carbon building measures for office buildings in Hong Kong. *International Journal of Energy Sector Management*, 8(4), 456–476.

APPENDIX A: DATA COLLECTION LETTER



Ministry of Education
King Fahd University of Petroleum & Minerals
COLLEGE OF ENVIRONMENTAL DESIGN
Dept. of Construction Engineering & Management
(036)

وزارة التعليم
جامعة الملك فهد للبترول والمعادن
كلية تصميم البيئة
قسم هندسة وإدارة التشييد
(٠٣٦)

To whom it may concern

We would like to inform that Mr. Hamza Basel Hamida (Academic number: G201215140) is a student in the program of the Master of Science in Construction Engineering and Management at King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. He works now in a research related to the curtain wall systems in office buildings. Therefore, he needs to gather as well as obtain various types of data and information (such as common types of curtain wall systems used in office buildings, criteria influencing the selection process of curtain wall systems, as well as costs and performance properties of different curtain wall systems) for office buildings. In this regard, kindly we wish from you to support Mr. Hamza with the information needed to accomplish his study.

Best Regards

Dr. Khalaf Al-Ofi
Chairman of Construction Engineering and Management Department
King Fahd University of Petroleum and Minerals
Dhahran, Saudi Arabia

لمن يهمه الأمر

نود إفادتكم بأن السيد حمزة باسل حميدة و رقمه الأكاديمي (201215140) طالب برنامج الماجستير في علوم هندسة وإدارة التشييد بجامعة الملك فهد للبترول والمعادن بالظهران بالمملكة العربية السعودية ، حيث إنه يعمل حالياً بدراسة تتعلق بأنظمة الحوائط الستائرية بمباني المكاتب ، لذلك فإنه بحاجة لجمع والحصول على البيانات والمعلومات المختلفة مثل الأنواع الشائعة لأنظمة الحوائط الستائرية التي تستخدم لمباني المكاتب ، و المعايير التي تؤثر على عملية اختيار أنظمة الحوائط الستائرية ، و أيضا التكاليف و خصائص الأداء لأنظمة الحوائط الستائرية المختلفة، ومن هذا المنطلق نأمل من سعادتكم دعم السيد حمزة بالمعلومات الكافية كي يتمكن من إتمام دراسته.

وتقبلوا خالص التحية والتقدير
د/ خلف العوفي
رئيس قسم هندسة وإدارة التشييد
جامعة الملك فهد للبترول والمعادن
الظهران ، المملكة العربية السعودية



27/3/2019



Figure A.1: Data collection letter

APPENDIX B: UNSTRUCTURED INTERVIEW FORM (ENGLISH)

Practices Adopted to Select and Design Curtain Wall Systems for Office Buildings in Saudi Arabia

1. Information of the Respondent (Optional)

Name	
Organization name	
Organization address	
Phone number	
Email address	

2. Technical Background of the Respondent

- ☐ Architecture
- ☐ Architectural/Building Engineering
- ☐ Civil/Construction Engineering
- ☐ Other (Please Specify) _____.

3. Years of Experience

- ☐ 5 years and less
- ☐ 5 to 10 years
- ☐ 10 to 20 years
- ☐ Over 20 years

4. The selection of curtain walls plays a vital role in different aspects of the building construction industry. In your opinion, how professionals working in design offices and consulting firms in the Eastern province of Saudi Arabia select a particular curtain wall system to be used in an office building?

APPENDIX C: UNSTRUCTURED INTERVIEW FORM (ARABIC)

الممارسات المتبعة لاختيار وتصميم أنظمة الحوائط الستائرية للمباني المكتبية في المملكة العربية السعودية

1. معلومات عن المجيب (إختياري)

	الاسم
	اسم المؤسسة
	عنوان المؤسسة
	رقم الجوال
	عنوان البريد الإلكتروني

2. الخلفية الفنية للمجيب

- ☐ عمارة
- ☐ هندسة معمارية أو مباني
- ☐ هندسة مدنية أو تشييد
- ☐ غير ذلك (يرجى التحديد) .

3. سنوات الخبرة

- ☐ 5 سنوات أو أقل
- ☐ من 5 إلى 10 سنوات
- ☐ من 10 إلى 20 سنة
- ☐ أكثر من 20 سنة

4. يلعب اختيار الحوائط الستائرية دورًا حيويًا في جوانب مختلفة بقطاع صناعة تشييد المباني. في رأيك ، كيف يختار المهنيون الذين يعملون بمؤسسات التصميم والإستشارات الهندسية بالمملكة العربية السعودية نوعا محددًا من أنظمة الحوائط الستائرية ليتم استخدامه بمبنى مكتبي؟

APPENDIX D: Summary of Unstructured Interviews

The following table summarizes the statements documented from the unstructured interviews.

Table D.1: Summary of unstructured interviews

Interview No.	Statements
1	• “Curtain walls are usually selected according to the project type, design and function” • “Many fundamentals play a significant role in selecting the curtain walls, such as thermal performance, acoustic, moisture performance, cost, structure, noise control, and fire resistance”
2	• “Generally it is based on the following criteria: 1. Architectural consideration 2. Economic consideration 3. Knowing how the system is available in the market”
3	• “The selection of a wall system considers module (units), cost, and thermal insulation”
4	• “The appearance of the system and how it matches with the design” • “The total cost of the system” • “The durability of the system”
5	• “The selection of the curtain wall considers important aspects that include the project details, budget cost, aesthetics, technical performance, and the experience of the supplier”
6	• “The selection is normally is done through the following considerations: 1. Available systems 2. The cost of systems 3. The ease of installation 4. The performance of the system • Other parameters may be considered depending on the nature of the project, such as acoustics in hotels and also the fire and wind resistance in office buildings”
7	• “It is firstly based on the A/E subjectivity about the aesthetic of the system. • The client budget limitations effect selecting a wall system. • The direction of the building and its height sometimes control the curtain wall selection due to the reflection of sun and wind effect. • Some clients prefer particular suppliers • The right designer is a major factor for the selection of suitable curtain wall system”

Figures D.1 to D.3 illustrate the interviewees' profile.

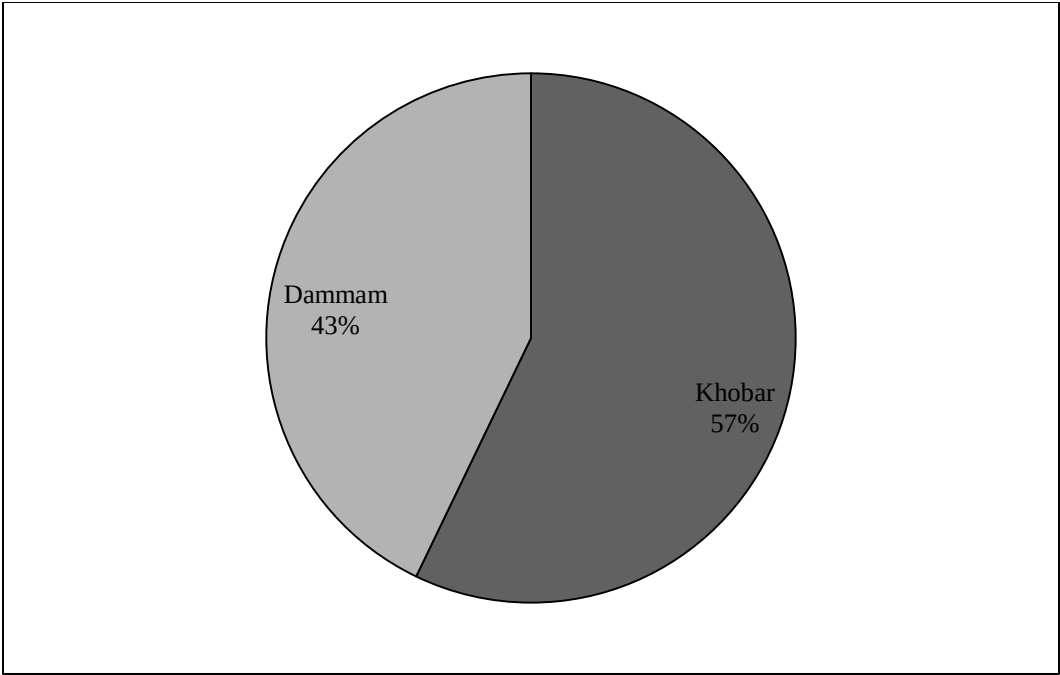


Figure D.1: Spatial distribution of interviewees

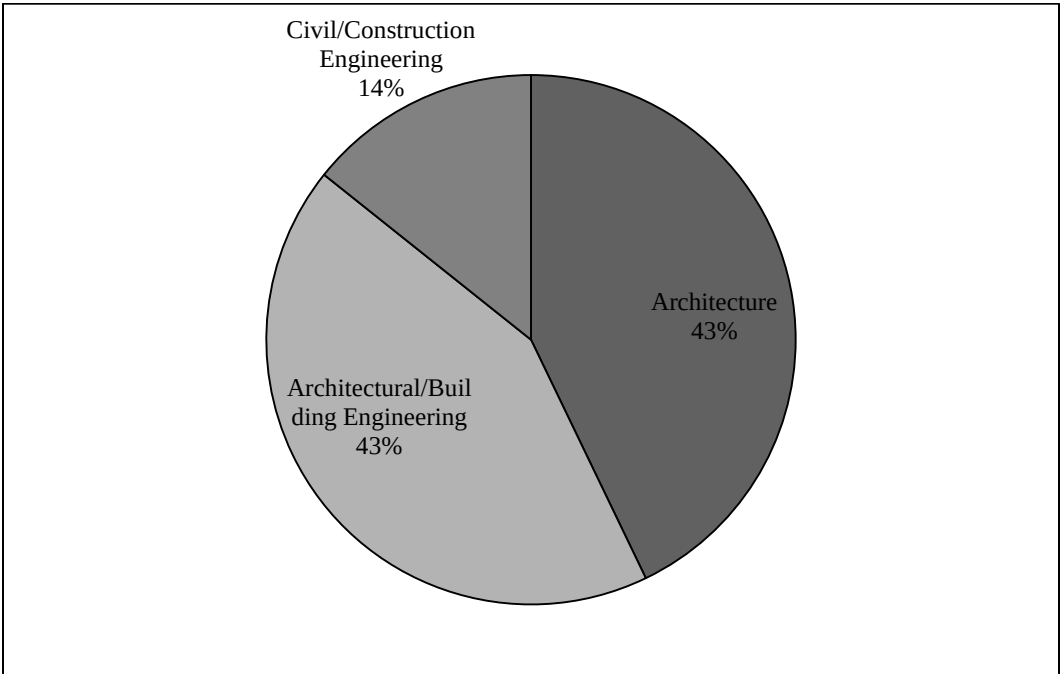


Figure D.2: Technical background distribution of the interviewees

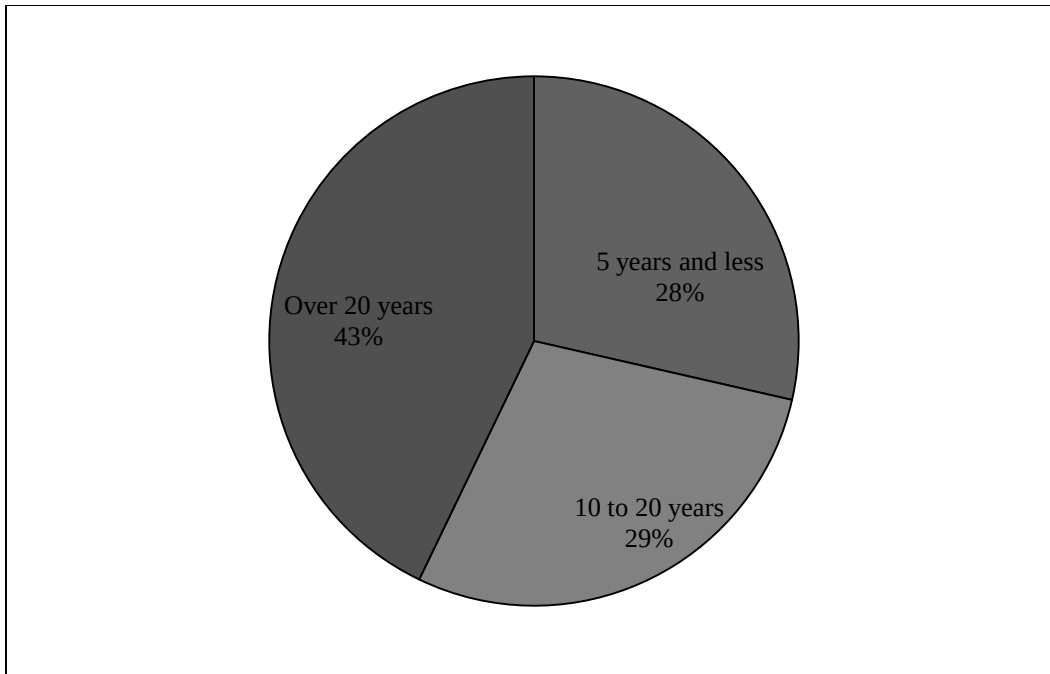


Figure D.3: Distribution of interviewees' years of experience

APPENDIX E: QUESTIONNAIRE SURVEY (ENGLISH)

AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings

Summary

Dear Sir,

The selection of curtain walls plays a vital role in the technical, economic, and socio-environmental aspects of office buildings and there are many alternatives of them which can be used. This study is based on a questionnaire to be filled by experts in the field of curtain wall systems. The survey consists of: (1) filling general information of the respondent section, (2) evaluating different criteria using pairwise comparison matrices, and (3) evaluating different curtain wall systems with respect to different criteria. It is appreciated that you fill the surveys as fully as possible.

This study is conducted by a researcher in the Department of Construction Engineering and Management (CEM) at King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia. Therefore, all information obtained from the surveys is confidential and will be used for research purposes.

Best Regards,

Hamza Basel Hamida,

Construction Engineering and Management Department,

King Fahd University of Petroleum and Minerals,

Dhahran, Saudi Arabia

Email: g201215140@kfupm.edu.sa

Mobile phone: +966530217690

Section (1): General Information

1. Information of the Respondent (Optional)

Name	
Organization name	
Organization address	
Phone number	
Email address	

2. Technical Background of the Respondent

- ☐ Architecture
- ☐ Architectural/Building Engineering
- ☐ Civil/Construction Engineering
- ☐ Other (Please Specify) _____.

3. Years of Experience

- ☐ 5 years and less
- ☐ 5 to 10 years
- ☐ 10 to 20 years
- ☐ Over 20 years

4. Have you been involved in the design or selection of curtain wall systems in office buildings?

- ☐ Yes ☐ No

*Please don't fill the surveys if you haven't been involved in these projects and kindly give the surveys to the person who is involved in these projects

Section (2): Evaluation of Criteria Influencing the Selection of Curtain Wall Systems

Kindly use the scale that ranges from 1 to 9 in the pairwise comparison matrices to evaluate the criteria influencing the selection of curtain wall systems in office buildings. The following examples illustrate the use of this scale:

	Criterion (A)	Criterion (B)
Criterion (A)	1	→ 1
Criterion (B)		1

The criterion (A) is equally preferred to (B)

	Criterion (A)	Criterion (B)
Criterion (A)	1	→ 9
Criterion (B)		1

The criterion (A) is extremely preferred to (B)

	Criterion (A)	Criterion (B)
Criterion (A)	1	→ 1/9
Criterion (B)		1

The criterion (B) is extremely preferred to (A)

1. The pairwise comparison matrix of major criteria group

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1		
Economic Criteria		1	
Socio-Environmental Criteria			1

2. The pairwise comparison matrix of technical criteria

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1							
Material Weight		1						
Fire Resistance			1					
Thermal Performance				1				
Acoustical Performance					1			
Water Tightness						1		
Air Tightness							1	
Simplicity of Design Details								1

3. The pairwise comparison matrix of economic criteria

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1						
Ease of Construction		1					
Initial Cost			1				
Maintenance Cost				1			
Durability (expected service life)					1		
Maintainability						1	
Availability of Materials from Local Suppliers							1

4. The pairwise comparison matrix of socio-environmental criteria

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1							
Control of Light		1						
Safety During and after Construction			1					
Disturbance of Community During Construction				1				
Energy Consumption through Required Construction Equipment					1			
Consumption of Materials						1		
Waste Generation							1	
Reusability/Recyclability of Materials								1

Section (3): Evaluation of Different Curtain Wall Systems Using MAUT

Kindly use the scale that ranges from 1 to 5 in the following table to evaluate different curtain wall systems based on different criteria.

Scale	Description
1	Not Preferred
2	Preferred Somewhat
3	Moderately Preferred
4	Very Preferred
5	Extremely Preferred

Figure 1 illustrates the stick curtain wall system which consists of the following:

- (1) Anchors
- (2) Mullions
- (3) Horizontal rails
- (4) Spandrel panels
- (5) Horizontal rails
- (6) Vision glass
- (7) Interior mullion trim

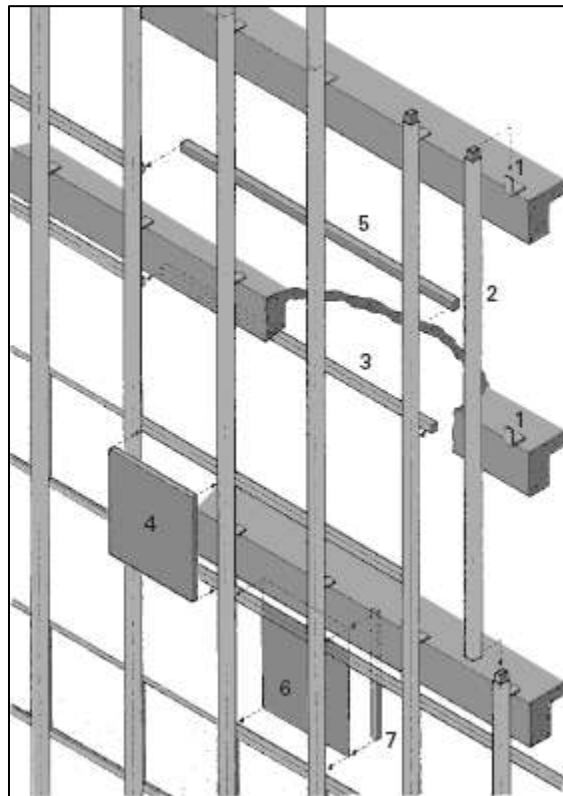


Figure 1: Stick System

Figure 2 illustrates the unitized curtain wall system which consists of the following:

- (1) Anchors
- (2) Preassembled framed units.

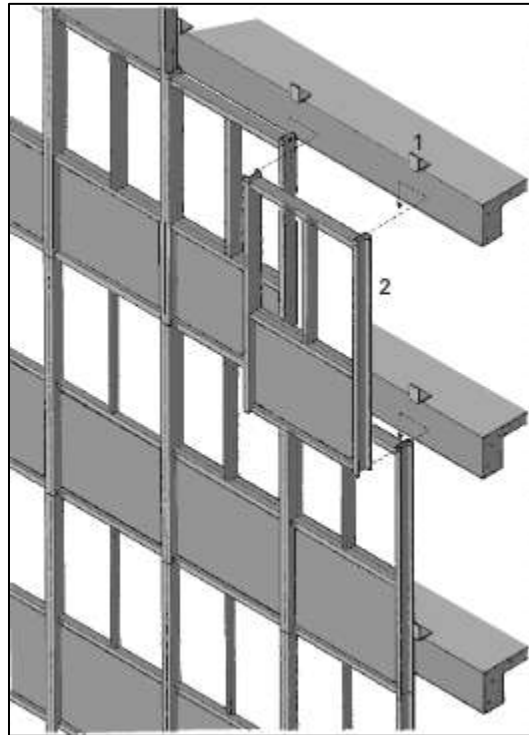


Figure 2: Unitized System

Figure 3 illustrates the unit-and-mullion curtain wall system which consists of the following:

- (1) Anchors
- (2) Mullions
- (3) Preamsembled units
- (4) Interior mullion trim

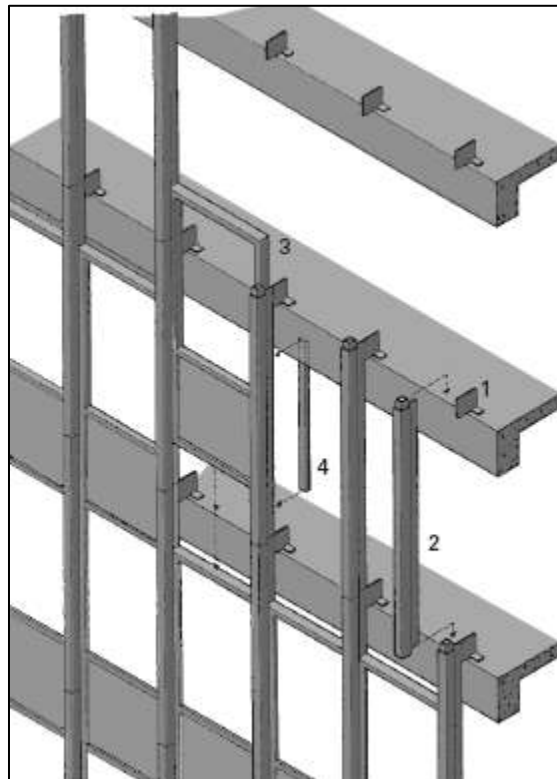


Figure 3: Unit-and-mullion system

Figure 4 illustrates the column-cover and spandrel curtain wall system which consists of the following:

- (1) Column covers
- (2) Spandrel panels
- (3) Glazing units

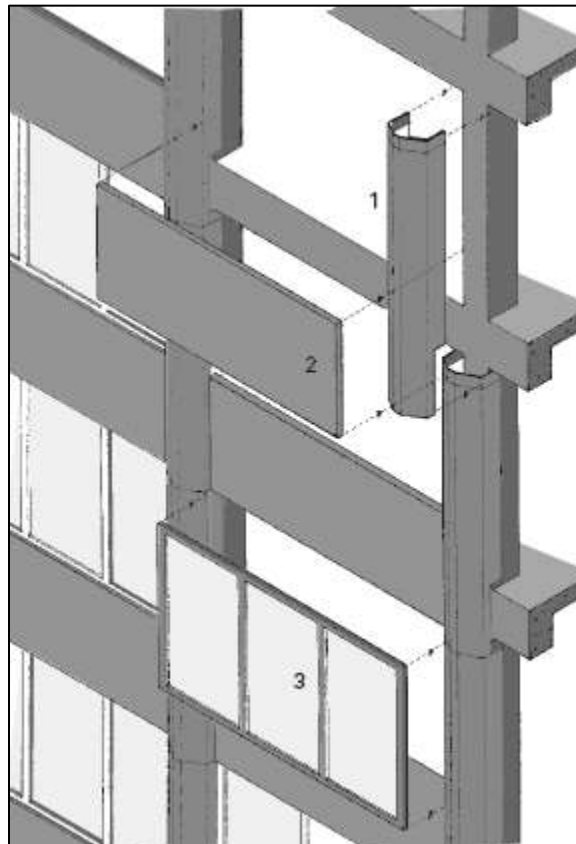


Figure 4: Column-cover-and -spandrel system

Figure 5 illustrates the spiders fixed to building frames that are used in structural standoff systems (Spider System)



Figure 5: Spiders fixed to building frames are used in structural standoff systems (Spider System)

Figure 6 illustrates a typical precast concrete wall cladding installation

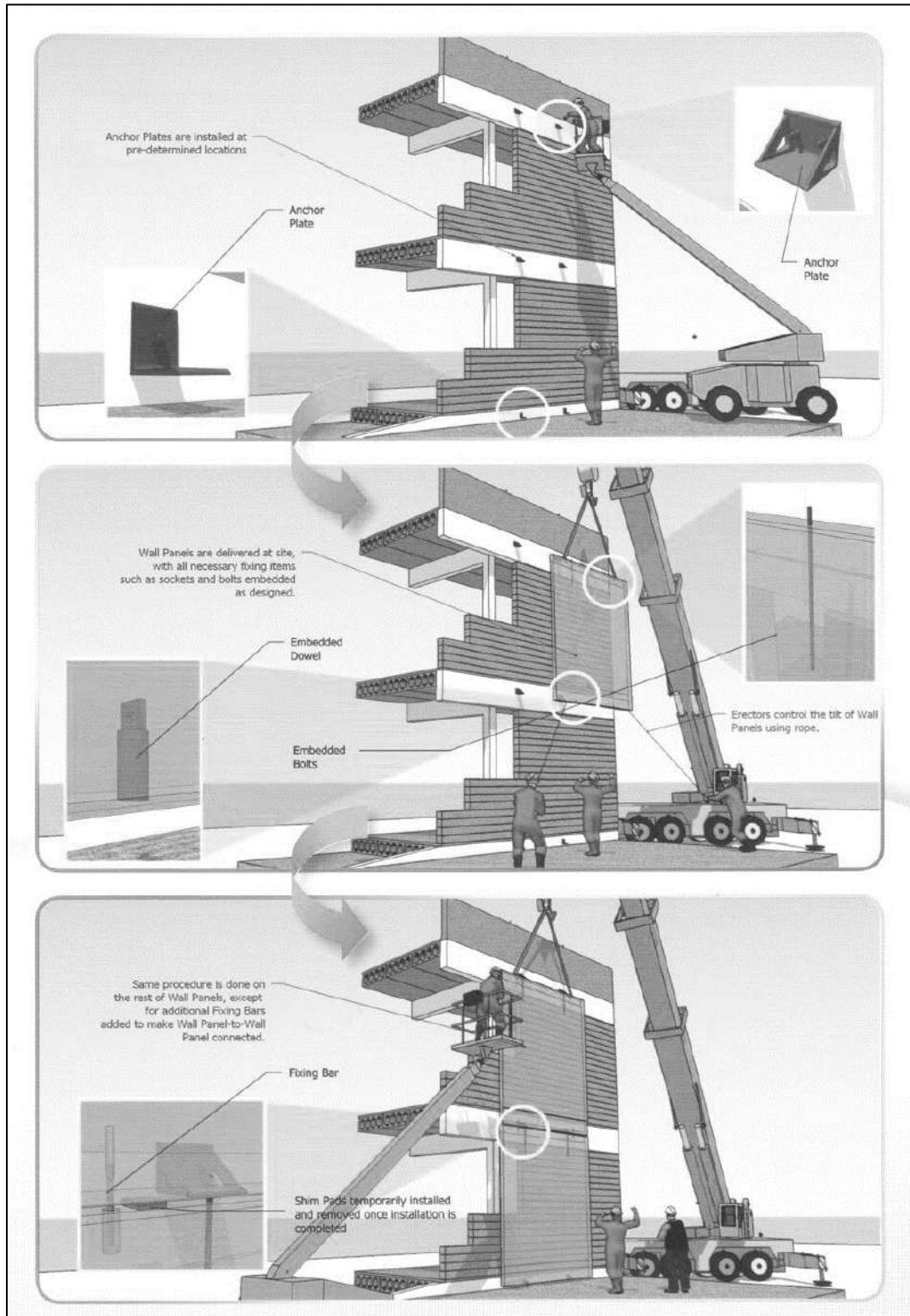


Figure 6: A typical precast concrete wall cladding installation

1. Evaluation of different curtain wall systems based on technical criteria

Category	Criteria	Metal and Glass Curtain Walls					Precast Concrete Cladding Panels (Figure 6)
		Stick Systems (Figure 1)	Unitized Systems (Figure 2)	Unit-and-Mullion Systems (Figure 3)	Column-Cover and Spandrel Systems (Figure. 4)	Point-Supported Glazing Systems (Spider System) (Figure 5)	
Technical Criteria	Wind Resistance						
	Material Weight						
	Fire Resistance						
	Thermal Performance						
	Acoustical Performance						
	Water Tightness						
	Air Tightness						
	Simplicity of Design Details						

2. Evaluation of different curtain wall systems based on economic criteria

Category	Criteria	Metal and Glass Curtain Walls					Precast Concrete Cladding Panels (Figure 6)
		Stick Systems (Figure 1)	Unitized Systems (Figure 2)	Unit-and-Mullion Systems (Figure 3)	Column-Cover and Spandrel Systems (Figure. 4)	Point-Supported Glazing Systems (Spider System) (Figure 5)	
Economic Criteria	Erection Time						
	Ease of Construction						
	Initial Cost						
	Maintenance Cost						
	Durability (expected service life)						
	Maintainability						
	Availability of Materials from Local Suppliers						

3. Evaluation of different curtain wall systems based on socio-environmental Criteria

Category	Criteria	Metal and Glass Curtain Walls					Precast Concrete Cladding Panels (Figure 6)
		Stick Systems (Figure 1)	Unitized Systems (Figure 2)	Unit-and-Mullion Systems (Figure 3)	Column-Cover and Spandrel Systems (Figure. 4)	Point-Supported Glazing Systems (Spider System) (Figure 5)	
Socio-Environmental Criteria	Aesthetics						
	Control of Light						
	Safety During and after Construction						
	Disturbance of Community During Construction						
	Energy Consumption through Required Construction Equipment						
	Consumption of Materials						
	Waste Generation						
	Reusability/Recyclability of materials						

APPENDIX F: QUESTIONNAIRE SURVEY (ARABIC)

نموذج قائم على أساس عملية التحليل الهرمي ونظرية المنفعة المتعددة الخصائص لاختيار أنظمة الحوائط الستائرية للمباني المكتبية

ملخص

أخي الكريم،

يلعب اختيار الحوائط الستائرية دورًا حيويًا في الجوانب الفنية والاقتصادية والاجتماعية والبيئية للمباني المكتبية ، حيث هنالك العديد من بدائل هذه الحوائط التي يمكن استخدامها.

إن هذه الدراسة مبنية على إسيان يتم الإجابة عليه من ذوي الخبرة في مجال الحوائط الستائرية ، ويتكون هذا الإستبيان من ثلاثة أقسام رئيسة وهي: قسم المعلومات العامة عن المحيبي ، وقسم تقييم المعايير باستخدام مصفوفات المقارنة الزوجية ، وقسم تقييم بدائل الحوائط الستائرية فيما يتعلق بالمعايير المختلفة ، لذلك فإن تعبئة هذا الإستبيان على أتم وجه لهو محل شكر وتقدير بالنسبة لنا.

يجري هذه الدراسة باحث بقسم هندسة وإدارة التشييد بجامعة الملك فهد للبترول والمعادن بمدينة الظهران ، ولذلك فإن جميع المعلومات التي يتم الحصول عليها من هذا الإستبيان يتم استخدامها للأغراض الأكاديمية والبحثية فقط

وتقبلوا خالص التحية والتقدير

حمزة باسل حميدة

قسم هندسة وإدارة التشييد

كلية تصاميم البيئة

جامعة الملك فهد للبترول والمعادن

الظهران- المملكة العربية السعودية

البريد الإلكتروني: g201215140@kfupm.edu.sa

الجوال: 0530217690

القسم الأول: المعلومات العامة

1. معلومات عن المجيب (إختياري)

الاسم	
اسم المؤسسة	
عنوان المؤسسة	
رقم الجوال	
عنوان البريد الإلكتروني	

2. الخلفية الفنية للمجيب

- ☐ عمارة
- ☐ هندسة معمارية أو مباني
- ☐ هندسة مدنية أو تشييد
- ☐ غير ذلك (يرجى التحديد) . _____

3. سنوات الخبرة

- ☐ 5 سنوات أو أقل
- ☐ من 5 إلى 10 سنوات
- ☐ من 10 إلى 20 سنة
- ☐ أكثر من 20 سنة

4. هل شاركت في تصميم أو اختيار أنظمة الحوائط الستائرية للمباني المكتبية ؟

- ☐ نعم ☐ لا
- * يرجى عدم الإجابة على هذا الإستبيان إذا لم تكن مشاركاً في هذا النوع من المشاريع ، ويرجى تقديمه إلى الشخص المشارك في هذه المشاريع

القسم الثاني: تقييم المعايير المؤثرة بعملية اختيار الحوائط الستائرية باستخدام عملية التحليل الهرمي

يرجى استخدام المقياس التالي والذي يتراوح من 1 إلى 9 في مصفوفات المقارنة الزوجية ولذلك لتقييم المعايير التي تؤثر على عملية اختيار أنظمة الحوائط الستائرية للمباني المكتبية ، الأمثلة التالية توضح استخدام هذا المقياس:

المعيار (ب)	المعيار (أ)	
1	1	المعيار (أ)
1		المعيار (ب)

أفضلية المعيار (أ) هي مساوية إلى المعيار (ب)

المعيار (ب)	المعيار (أ)	
9	1	المعيار (أ)
1		المعيار (ب)

يتم تفضيل المعيار (أ) للغاية على المعيار (ب)

المعيار (ب)	المعيار (أ)	
1/9	1	المعيار (أ)
1		المعيار (ب)

يتم تفضيل المعيار (ب) للغاية على المعيار (أ)

1. مصفوفة المقارنة الزوجية لمجموعة المعايير الرئيسية

المعايير الفنية	المعايير الفنية	المعايير الاقتصادية	المعايير الاجتماعية والبيئية
المعايير الفنية	1		
المعايير الاقتصادية		1	
المعايير الاجتماعية والبيئية			1

2. مصفوفة المقارنة الزوجية للمعايير الفنية

مقاومة الرياح	وزن المواد	مقاومة الحرائق	الأداء الحراري	الأداء الصوتي	عزل الماء	عزل الهواء	بساطة تفاصيل التصميم
مقاومة الرياح	1						
وزن المواد		1					
مقاومة الحرائق			1				
الأداء الحراري				1			
الأداء الصوتي					1		
عزل الماء						1	
عزل الهواء							1
بساطة تفاصيل التصميم							

3. مصفوفة المقارنة الزوجية للمعايير الإقتصادي

توافر المواد من الموردين المحليين	سهولة الصيانة	متانة المواد (العمر الخدمي المتوقع)	تكلفة الصيانة	التكلفة الأولية	سهولة التشييد	الوقت اللازم للتشييد	
						1	الوقت اللازم للتشييد
					1		سهولة التشييد
				1			التكلفة الأولية
			1				تكلفة الصيانة
		1					متانة المواد (العمر الخدمي المتوقع)
	1						سهولة الصيانة
1							توافر المواد من الموردين المحليين

4. مصفوفة المقارنة الزوجية للمعايير الاجتماعية والبيئية

الجماليات	الجماليات	التحكم بالإنارة	السلامة أثناء وبعد التشييد	إزعاج المجتمع المحيط أثناء التشييد	إستهلاك الطاقة من خلال معدات التشييد	إستهلاك المواد أثناء التشييد	المخلفات الناجمة أثناء التشييد	قابلية إعادة استخدام أو تدوير المواد
الجماليات	1							
التحكم بالإنارة		1						
السلامة أثناء وبعد التشييد			1					
إزعاج المجتمع المحيط أثناء التشييد				1				
إستهلاك الطاقة من خلال معدات التشييد					1			
إستهلاك المواد أثناء التشييد						1		
المخلفات الناتجة أثناء التشييد							1	
قابلية إعادة استخدام أو تدوير المواد								1

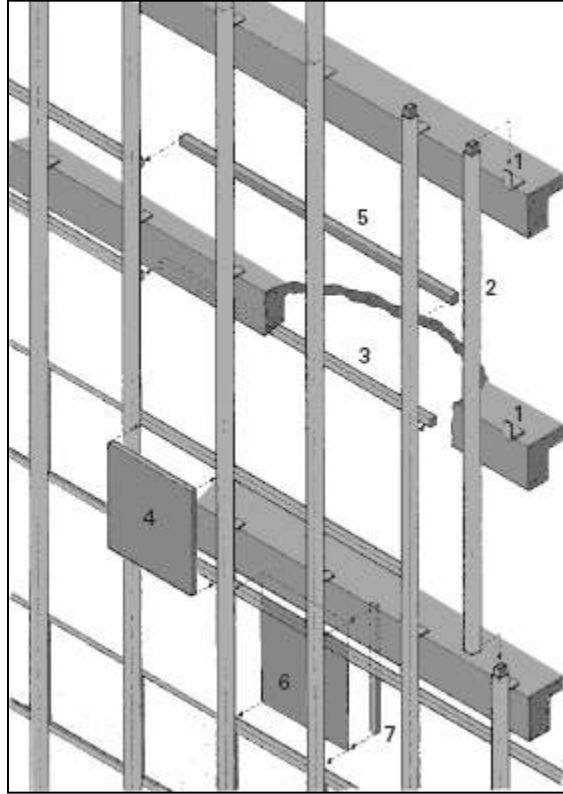
القسم الثالث: تقييم بدائل الحوائط الستائرة باستخدام نظرية المنفعة المتعددة الخصائص

يرجى استخدام المقياس الذي يتراوح من 1 إلى 5 في الجدول التالي وذلك لتقييم أنظمة الحوائط الستائيرة المختلفة بناءً على المعايير المختلفة

المقياس	الشرح
1	غير مفضل
2	مفضل إلى حد ما
3	مفضل بشكل معتدل
4	مفضل جداً
5	مفضل للغاية

الشكل 1 يوضح نظام اللصق والذي يتكون من التالي:

- (1) وصلات الربط
- (2) المحاور المفصلية الرأسية
- (3) المحاور المفصلية العرضية
- (4) الألواح العاتمة
- (5) المحاور المفصلية العرضية
- (7) المحاور المفصلية الرأسية الداخلية

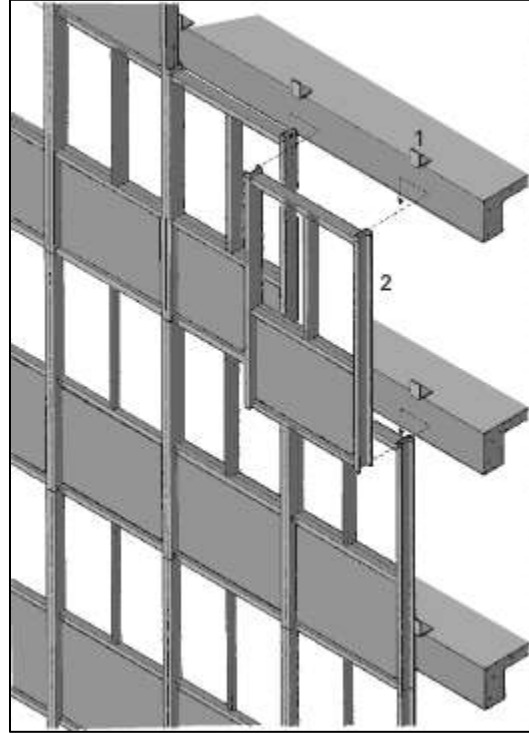


الشكل 1: نظام اللصق

الشكل 2 يوضح نظام الوحدات والذي يتكون من التالي:

(1) وصلات الربط

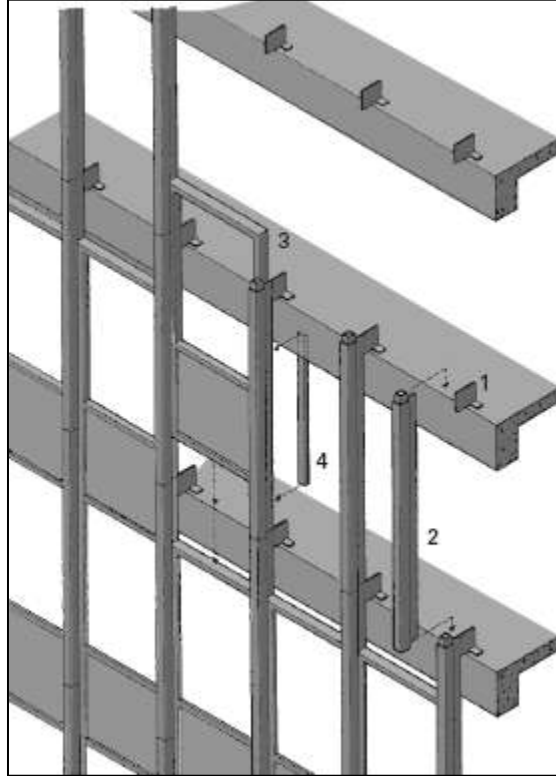
(2) الوحدات المؤطرة مسبقة التجميع



الشكل 2: نظام الوحدات

الشكل 3 يوضح نظام الوحدة والفواصل والذي يتكون من التالي:

- (1) وصلات الربط
- (2) المحاور المفصلية الرأسية
- (3) وحدات مسبقة التجميع
- (4) المحاور المفصلية الرأسية الداخلية



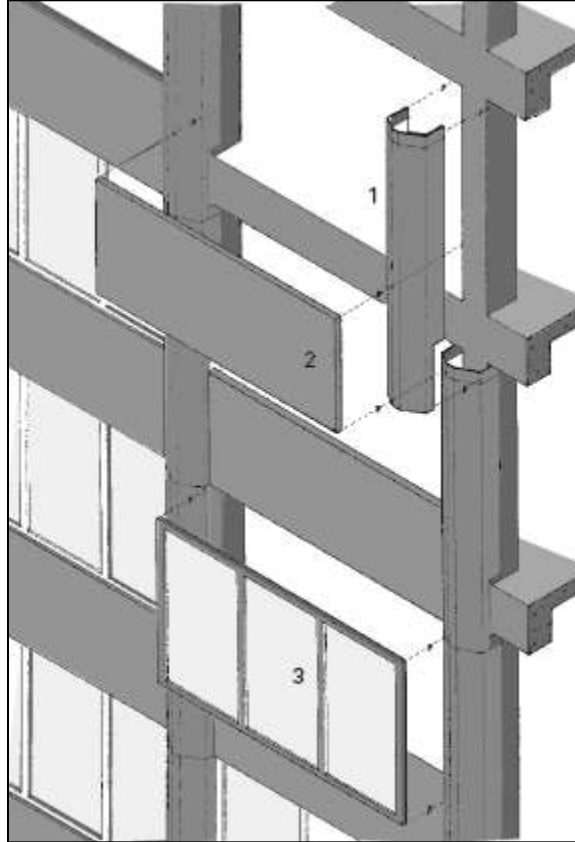
الشكل 3: نظام الوحدة والفواصل

الشكل 4 يوضح نظام غطاء العمود والزجاج العاتم والذي يتكون من التالي:

(1) أغطية الأعمدة

(2) الألواح العاتمة

(3) الوحدات الزجاجية



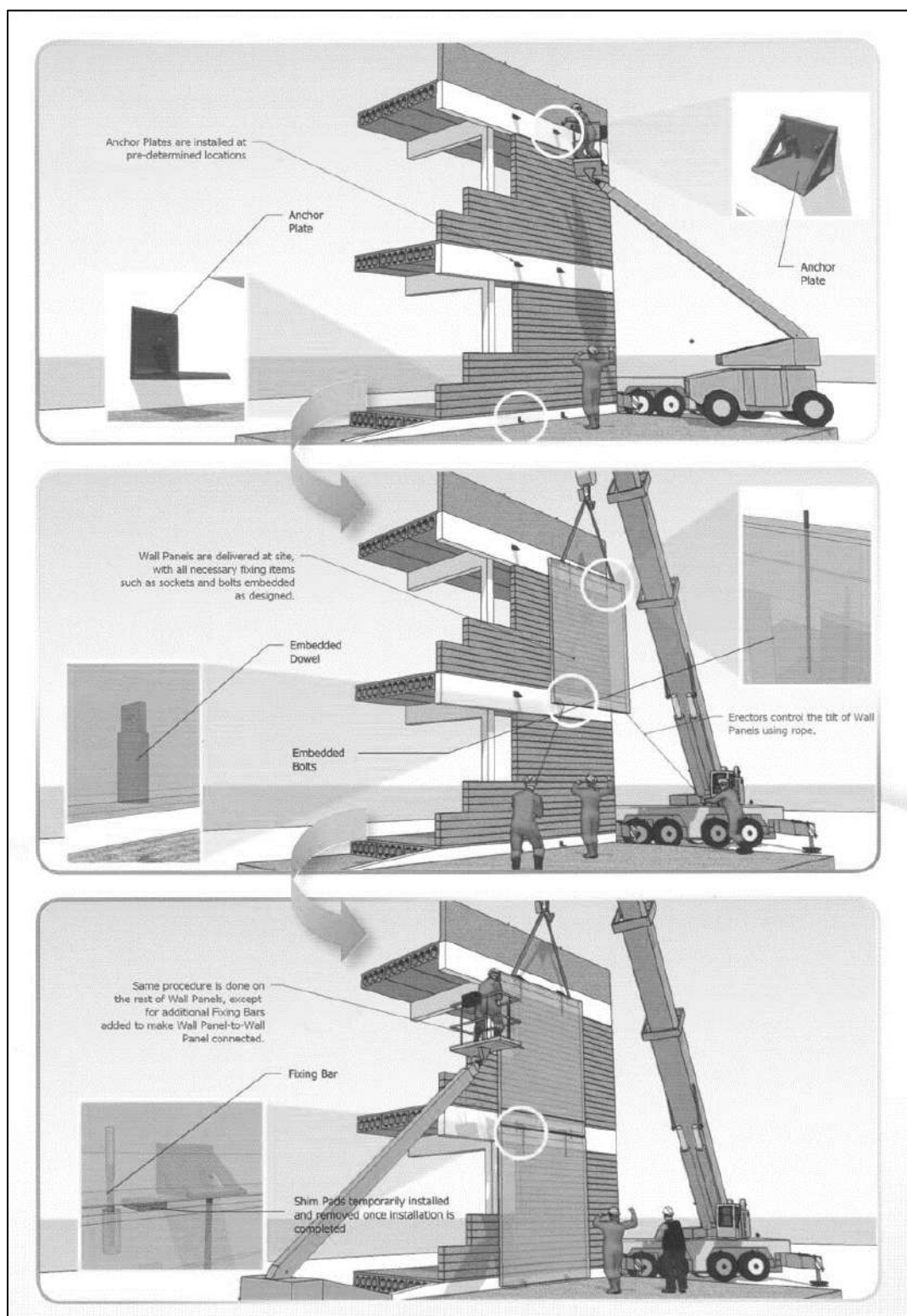
الشكل 4: نظام غطاء العمود والزجاج العاتم

الشكل 5 يوضح المثبتات العنكبوتية المثبتة على إطارات المباني



الشكل 5: المثبتات العنكبوتية

الشكل 6 يوضح تركيب ألواح التغطية المصنوعة من الخرسانة المسبقة الصب



الشكل 6: تركيب ألواح التغطية المصنوعة من الخرسانة المسبقة الصب

1. تقييم أنظمة الحوائط الستائرية المختلفة بناءً على المعايير الفنية

الترتيب	المعايير	الحوائط الستائرية المصنوعة من المعدن والزجاج					ألواح التغطية المصنوعة من الخرسانة المسبقة الصب (شكل 6)
		نظام اللصق (شكل 1)	نظام الوحدات (شكل 2)	نظام الوحدة والفواصل (شكل 3)	نظام غطاء العمود والزجاج العائم (شكل 4)	نظام الزجاج المثبت بنقطة (نظام التثبيت العنكبوتي) (شكل 5)	
المعايير الفنية	مقاومة الرياح						
	وزن المواد						
	مقاومة الحرائق						
	الأداء الحراري						
	الأداء الصوتي						
	عزل الماء						
	عزل الهواء						
	بساطة تفاصيل التصميم						

2. تقييم أنظمة الحوائط الستائرية المختلفة بناءً على المعايير الاقتصادية

الفترة	المعايير	الحوائط الستائرية المصنوعة من المعدن والزجاج					ألواح التغطية المصنوعة من الخرسانة المسبقة الصب (شكل 6)
		نظام اللصق (شكل 1)	نظام الوحدات (شكل 2)	نظام الوحدة والفواصل (شكل 3)	نظام غطاء العمود والزجاج العائم (شكل 4)	نظام الزجاج المثبت بنقطة (نظام التثبيت العنكبوتي) (شكل 5)	
المعايير الاقتصادية	الوقت اللازم للتشييد						
	سهولة التشييد						
	التكلفة الأولية						
	تكلفة الصيانة						
	متانة المواد (العمر الخدمي المتوقع)						
	سهولة الصيانة						
	توافر المواد من الموردين المحليين						

3. تقييم أنظمة الحوائط الستائرية المختلفة بناءً على المعايير الإجتماعية والبيئية

المعايير	الحوائط الستائرية المصنوعة من المعدن والزجاج					المعايير
	نظام الزجاج المثبت بنقطة (نظام التثبيت العنكبوتي) (شكل 5)	نظام غطاء العمود والزجاج العائم (شكل 4)	نظام الوحدة والفواصل (شكل 3)	نظام الوحدات (شكل 2)	نظام اللصق (شكل 1)	
المعايير الاجتماعية والبيئية	ألواح التكبسية المصنوعة من الخرسانة المسبقة الصب (شكل 6)					الجماليات
						التحكم بالإضاءة
						السلامة أثناء وبعد التشييد
						إزعاج المجتمع المحيط أثناء البناء
						إستهلاك الطاقة من خلال معدات التشييد
						إستهلاك المواد أثناء التشييد
						المخلفات الناتجة أثناء التشييد
						قابلية إعادة استخدام أو تدوير المواد

APPENDIX G: ANALYSIS OF AHP DATA USING EXPERT CHOICE SOFTWARE

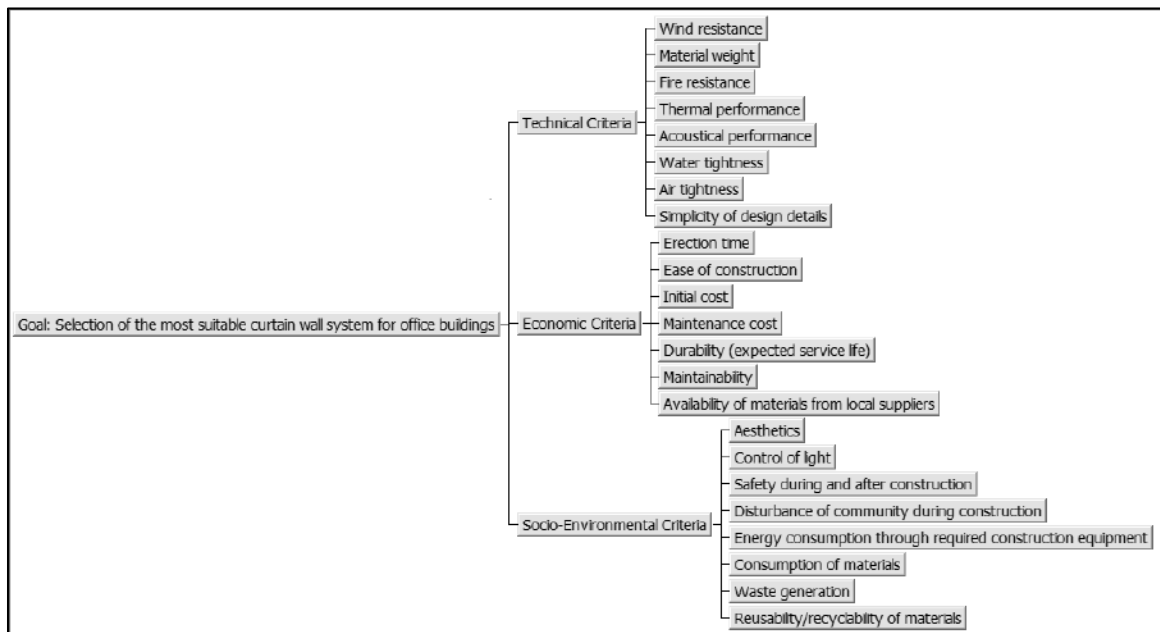


Figure G.1: Structural hierarchy in Expert Choice Software

Technical Criteria	9 8 7 6 5 4 3 2 2 3 4 5 6 7 8 9 	Socio-Environmental Criteria	
Compare the relative importance with respect to: Goal: Selection of the most suitable curtain wall system for office buildings			
	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria			
Economic Criteria			
Socio-Environmental Criteria			

Figure G.2: Pairwise comparison matrix of major criteria group in Expert Choice Software

Wind resistance	9 8 7 6 5 4 3 2 2 3 4 5 6 7 8 9 	Water tightness						
Compare the relative importance with respect to: Technical Criteria								
	Wind resistance	Material weight	Fire resistance	Thermal performance	Acoustical performance	Water tightness	Air tightness	Simplicity of design details
Wind resistance								
Material weight								
Fire resistance								
Thermal performance								
Acoustical performance								
Water tightness								
Air tightness								
Simplicity of design details								

Figure G.3: Pairwise comparison matrix of technical criteria in Expert Choice Software

Erection time	98765432123456789	Ease of construction					
Compare the relative importance with respect to: Economic Criteria							
	Erection time	Ease of construction	Initial cost	Maintenance cost	Durability (expected service life)	Maintainability	Availability of materials
Erection time							
Ease of construction							
Initial cost							
Maintenance cost							
Durability (expected service life)							
Maintainability							
Availability of materials from local suppliers							

Figure G.4: Pairwise comparison matrix of economic criteria in Expert Choice Software

Aesthetics		98765432123456789 																Control of light	
Compare the relative importance with respect to: Socio-Environmental Criteria																			
	Aesthetics	Control of light	Safety during	Disturbance of community	Energy consumption	Consumption of	Waste gen	Reusability/recyclab											
Aesthetics																			
Control of light																			
Safety during and after construction																			
Disturbance of community during construction																			
Energy consumption through required construction equipment																			
Consumption of materials																			
Waste generation																			
Reusability/recyclability of materials																			

Figure G.5: Pairwise comparison matrix of socio-environmental criteria in Expert Choice Software

APPENDIX H: CONSISTENT RESPONSES FROM AHP ANALYSIS

H.1 Consistent results obtained from respondent No. 2

Table H.1: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 2

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	2	4
Economic Criteria		1	4
Socio-Environmental Criteria			1
CR = 0.05			

Table H.2: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 2

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	6	1	4	7	1	1	3
Material Weight		1	1/8	1/7	1	1/3	1/3	1
Fire Resistance			1	4	5	3	3	4
Thermal Performance				1	4	1	1	1
Acoustical Performance					1	1	1	1/3
Water Tightness						1	1	4
Air Tightness							1	4
Simplicity of Design Details								1
CR = 0.09								

Table H.3: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 2

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1	1/2	1/3	1/5	1/4	1/8
Ease of Construction		1	1	1/4	1/5	1/5	1/8
Initial Cost			1	1	¼	1/3	1/8
Maintenance Cost				1	½	1/2	1/3
Durability (expected service life)					1	3	1
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.04							

Table H.4: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 2

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/3	1/7	3	1/2	½	2	2
Control of Light		1	1/8	2	2	3	2	5
Safety During and after Construction			1	8	7	7	6	7
Disturbance of Community During Construction				1	1	1/3	1	1
Energy Consumption through Required Construction Equipment					1	1	½	1
Consumption of Materials						1	3	4
Waste Generation							1	5
Reusability/Recyclability of Materials								1
CR = 0.09								

Table H.5: Weight of criteria obtained from respondent No. 2

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.547	Wind Resistance	0.219	0.120
		Material Weight	0.036	0.020
		Fire Resistance	0.276	0.151
		Thermal Performance	0.112	0.061
		Acoustical Performance	0.052	0.028
		Water Tightness	0.121	0.066
		Air Tightness	0.121	0.066
		Simplicity of Design Details	0.064	0.035
		Total	1.001	0.547
Economic Criteria	0.345	Erection Time	0.039	0.013
		Ease of Construction	0.040	0.014
		Initial Cost	0.062	0.021
		Maintenance Cost	0.106	0.037
		Durability (expected service life)	0.270	0.093
		Maintainability	0.182	0.063
		Availability of Materials from Local Suppliers	0.301	0.104
		Total	1.000	0.345
Socio-Environmental Criteria	0.109	Aesthetics	0.069	0.008
		Control of Light	0.139	0.015
		Safety During and after Construction	0.477	0.052
		Disturbance of Community During Construction	0.045	0.005
		Energy Consumption through Required Construction Equipment	0.062	0.007
		Consumption of Materials	0.101	0.011
		Waste Generation	0.071	0.008
		Reusability/Recyclability of materials	0.039	0.004
Total	1.001	Total	1.003	0.109

H.2 Consistent results obtained from respondent No. 3

Table H.6: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 3

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1/4	3
Economic Criteria		1	5
Socio-Environmental Criteria			1
CR = 0.08			

Table H.7: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 3

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	4	1	1	4	2	4	4
Material Weight		1	1/5	1/5	1/4	1/5	¼	4
Fire Resistance			1	1	5	4	3	6
Thermal Performance				1	4	2	4	4
Acoustical Performance					1	1/4	1	1
Water Tightness						1	4	4
Air Tightness							1	1
Simplicity of Design Details								1
CR = 0.09								

Table H.8: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 3

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	3	2	1/3	1/5	1	1
Ease of Construction		1	1/5	1/5	1/8	1/5	1/7
Initial Cost			1	1	1	1	1
Maintenance Cost				1	1/3	1	1
Durability (expected service life)					1	3	3
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.06							

Table H.9: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 3

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	3	1/2	2	2	2	3	3
Control of Light		1	1/2	2	3	3	3	1
Safety During and after Construction			1	1	3	3	3	3
Disturbance of Community During Construction				1	2	2	2	2
Energy Consumption through Required Construction Equipment					1	1	2	2
Consumption of Materials						1	2	2
Waste Generation							1	3
Reusability/Recyclability of Materials								1
CR = 0.07								

Table H.10: Weight of criteria obtained from respondent No. 3

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.226	Wind Resistance	0.199	0.045
		Material Weight	0.045	0.010
		Fire Resistance	0.245	0.055
		Thermal Performance	0.204	0.046
		Acoustical Performance	0.060	0.014
		Water Tightness	0.144	0.033
		Air Tightness	0.063	0.014
		Simplicity of Design Details	0.040	0.009
		Total	1.000	0.226
Economic Criteria	0.674	Erection Time	0.112	0.075
		Ease of Construction	0.027	0.018
		Initial Cost	0.141	0.095
		Maintenance Cost	0.149	0.100
		Durability (expected service life)	0.325	0.219
		Maintainability	0.119	0.080
		Availability of Materials from Local Suppliers	0.127	0.086
		Total	1.000	0.673
Socio-Environmental Criteria	0.101	Aesthetics	0.201	0.020
		Control of Light	0.155	0.016
		Safety During and after Construction	0.223	0.023
		Disturbance of Community During Construction	0.128	0.013
		Energy Consumption through Required Construction Equipment	0.082	0.008
		Consumption of Materials	0.082	0.008
		Waste Generation	0.068	0.007
		Reusability/Recyclability of materials	0.061	0.006
Total	1.001	Total	1.000	0.101

H.3 Consistent results obtained from respondent No. 4

Table H.11: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 4

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	2	3
Economic Criteria		1	3
Socio-Environmental Criteria			1
CR = 0.05			

Table H.12: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 4

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	4	3	2	4	4	3	5
Material Weight		1	1/3	2	1/2	3	3	3
Fire Resistance			1	2	3	2	2	4
Thermal Performance				1	1/3	3	3	4
Acoustical Performance					1	3	3	4
Water Tightness						1	1/2	1/2
Air Tightness							1	1/2
Simplicity of Design Details								1
CR = 0.09								

Table H.13: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 4

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Ease of Construction		1	1	$\frac{1}{2}$	1	1	$\frac{1}{2}$
Initial Cost			1	1	$\frac{1}{3}$	$\frac{1}{2}$	2
Maintenance Cost				1	$\frac{1}{2}$	1	3
Durability (expected service life)					1	3	3
Maintainability						1	3
Availability of Materials from Local Suppliers							1
CR = 0.07							

Table H.14: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 4

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1/2	2	1	½	1/2	1
Control of Light		1	1	2	2	½	2	2
Safety During and after Construction			1	1	1	3	2	2
Disturbance of Community During Construction				1	1	1/3	1	1/2
Energy Consumption through Required Construction Equipment					1	1	1	1/3
Consumption of Materials						1	1	1
Waste Generation							1	1/3
Reusability/Recyclability of Materials								1
CR = 0.08								

Table H.15: Weight of criteria obtained from respondent No. 4

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.528	Wind Resistance	0.302	0.159
		Material Weight	0.110	0.058
		Fire Resistance	0.187	0.099
		Thermal Performance	0.106	0.056
		Acoustical Performance	0.148	0.078
		Water Tightness	0.043	0.023
		Air Tightness	0.054	0.029
		Simplicity of Design Details	0.051	0.027
		Total	1.001	0.529
Economic Criteria	0.333	Erection Time	0.071	0.024
		Ease of Construction	0.124	0.041
		Initial Cost	0.120	0.040
		Maintenance Cost	0.166	0.055
		Durability (expected service life)	0.262	0.087
		Maintainability	0.160	0.053
		Availability of Materials from Local Suppliers	0.098	0.033
		Total	1.001	0.333
Socio-Environmental Criteria	0.140	Aesthetics	0.099	0.014
		Control of Light	0.153	0.021
		Safety During and after Construction	0.186	0.026
		Disturbance of Community During Construction	0.080	0.011
		Energy Consumption through Required Construction Equipment	0.094	0.013
		Consumption of Materials	0.147	0.021
		Waste Generation	0.095	0.013
		Reusability/Recyclability of materials	0.147	0.021
Total	1.001	Total	1.001	0.140

H.4 Consistent results obtained from respondent No. 5

Table H.16: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 5

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1	4
Economic Criteria		1	4
Socio-Environmental Criteria			1
CR = 0.00			

Table H.17: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 5

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	6	1	7	6	6	6	5
Material Weight		1	1/9	1	1/5	1/2	1/2	1
Fire Resistance			1	2	2	1	1	2
Thermal Performance				1	1	1	1	2
Acoustical Performance					1	1/2	1/2	2
Water Tightness						1	1	2
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.07								

Table H.18: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 5

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1/3	1/2	1/3	1/3	1/3	2
Ease of Construction		1	1/3	1/3	1/3	1/3	2
Initial Cost			1	1/2	½	1/2	2
Maintenance Cost				1	½	1	1
Durability (expected service life)					1	1	1
Maintainability						1	2
Availability of Materials from Local Suppliers							1
CR = 0.09							

Table H.19: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 5

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1/2	2	2	1	1	4
Control of Light		1	1/3	2	4	5	4	5
Safety During and after Construction			1	6	7	5	5	7
Disturbance of Community During Construction				1	2	½	2	2
Energy Consumption through Required Construction Equipment					1	1/3	1/4	1
Consumption of Materials						1	1	1
Waste Generation							1	1/2
Reusability/Recyclability of Materials								1
CR = 0.07								

Table H.20: Weight of criteria obtained from respondent No. 5

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.444	Wind Resistance	0.376	0.167
		Material Weight	0.042	0.019
		Fire Resistance	0.178	0.079
		Thermal Performance	0.074	0.033
		Acoustical Performance	0.083	0.037
		Water Tightness	0.099	0.044
		Air Tightness	0.099	0.044
		Simplicity of Design Details	0.050	0.022
		Total	1.001	0.444
Economic Criteria	0.444	Erection Time	0.073	0.032
		Ease of Construction	0.097	0.043
		Initial Cost	0.138	0.061
		Maintenance Cost	0.177	0.079
		Durability (expected service life)	0.214	0.095
		Maintainability	0.204	0.091
		Availability of Materials from Local Suppliers	0.096	0.043
		Total	0.999	0.444
Socio-Environmental Criteria	0.111	Aesthetics	0.127	0.014
		Control of Light	0.197	0.022
		Safety During and after Construction	0.353	0.039
		Disturbance of Community During Construction	0.077	0.009
		Energy Consumption through Required Construction Equipment	0.039	0.004
		Consumption of Materials	0.082	0.009
		Waste Generation	0.071	0.008
		Reusability/Recyclability of materials	0.055	0.006
Total	0.999	Total	1.001	0.111

H.5 Consistent results obtained from respondent No. 6

Table H.21: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 6

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1	3
Economic Criteria		1	3
Socio-Environmental Criteria			1
CR = 0.00			

Table H.22: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 6

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	3	1	1	3	1	1	1
Material Weight		1	1/2	1/3	1/2	1/6	1/5	1
Fire Resistance			1	1	2	1	1	1
Thermal Performance				1	2	1	1	2
Acoustical Performance					1	1/3	1	1/2
Water Tightness						1	1	3
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.04								

Table H.23: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 6

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1	1/2	1/2	½	1/2	1
Ease of Construction		1	1/2	1/2	1	1	2
Initial Cost			1	1	½	1/3	1/2
Maintenance Cost				1	1	1	1/2
Durability (expected service life)					1	2	1
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table H.24: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 6

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1/2	1/2	2	2	2	2
Control of Light		1	1/2	1/2	1/2	½	1/2	3
Safety During and after Construction			1	2	2	2	2	2
Disturbance of Community During Construction				1	1/2	½	1/2	2
Energy Consumption through Required Construction Equipment					1	1	2	2
Consumption of Materials						1	2	1
Waste Generation							1	2
Reusability/Recyclability of Materials								1
CR = 0.08								

Table H.25: Weight of criteria obtained from respondent No. 6

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.429	Wind Resistance	0.149	0.064
		Material Weight	0.049	0.021
		Fire Resistance	0.134	0.057
		Thermal Performance	0.152	0.065
		Acoustical Performance	0.076	0.033
		Water Tightness	0.190	0.082
		Air Tightness	0.154	0.066
		Simplicity of Design Details	0.095	0.041
		Total	0.999	0.429
Economic Criteria	0.429	Erection Time	0.091	0.039
		Ease of Construction	0.134	0.057
		Initial Cost	0.124	0.053
		Maintenance Cost	0.150	0.064
		Durability (expected service life)	0.180	0.077
		Maintainability	0.163	0.070
		Availability of Materials from Local Suppliers	0.158	0.068
		Total	1.000	0.429
Socio-Environmental Criteria	0.143	Aesthetics	0.146	0.021
		Control of Light	0.089	0.013
		Safety During and after Construction	0.205	0.029
		Disturbance of Community During Construction	0.115	0.016
		Energy Consumption through Required Construction Equipment	0.138	0.020
		Consumption of Materials	0.130	0.019
		Waste Generation	0.110	0.016
		Reusability/Recyclability of materials	0.067	0.010
Total	1.001	Total	1.000	0.143

H.6 Consistent results obtained from respondent No. 7

Table H.26: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 7

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1	1
Economic Criteria		1	1/2
Socio-Environmental Criteria			1
CR = 0.05			

Table H.27: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 7

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	1	2	1/2	1	1	1	2
Material Weight		1	1/3	1/2	1/3	1/2	1/2	1
Fire Resistance			1	1/2	1/2	1	1	3
Thermal Performance				1	1	1	1	3
Acoustical Performance					1	1	1	2
Water Tightness						1	1	4
Air Tightness							1	3
Simplicity of Design Details								1
CR = 0.03								

Table H.28: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 7

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1	1	2	1/3	1/3	1
Ease of Construction		1	1	3	1/4	1	1
Initial Cost			1	1	1/3	1/3	1
Maintenance Cost				1	1	1	1
Durability (expected service life)					1	1	4
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table H.29: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 7

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1	2	1	1	2	3
Control of Light		1	2	1	1	2	4	1
Safety During and after Construction			1	1	1	1/2	1	1
Disturbance of Community During Construction				1	1/3	1/2	1	1/4
Energy Consumption through Required Construction Equipment					1	1	1	1/2
Consumption of Materials						1	1	1/2
Waste Generation							1	1/2
Reusability/Recyclability of Materials								1
CR = 0.07								

Table H.30: Weight of criteria obtained from respondent No. 7

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.327	Wind Resistance	0.131	0.043
		Material Weight	0.070	0.023
		Fire Resistance	0.123	0.040
		Thermal Performance	0.173	0.057
		Acoustical Performance	0.159	0.052
		Water Tightness	0.149	0.049
		Air Tightness	0.142	0.046
		Simplicity of Design Details	0.054	0.018
		Total	1.001	0.327
Economic Criteria	0.260	Erection Time	0.105	0.027
		Ease of Construction	0.133	0.035
		Initial Cost	0.091	0.024
		Maintenance Cost	0.112	0.029
		Durability (expected service life)	0.274	0.071
		Maintainability	0.182	0.047
		Availability of Materials from Local Suppliers	0.104	0.027
		Total	1.001	0.260
Socio-Environmental Criteria	0.413	Aesthetics	0.172	0.071
		Control of Light	0.168	0.069
		Safety During and after Construction	0.099	0.041
		Disturbance of Community During Construction	0.075	0.031
		Energy Consumption through Required Construction Equipment	0.123	0.051
		Consumption of Materials	0.116	0.048
		Waste Generation	0.081	0.033
		Reusability/Recyclability of materials	0.165	0.068
Total	1.000	Total	0.999	0.413

H.7 Consistent results obtained from respondent No. 8

Table H.31: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 8

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1/2	5
Economic Criteria		1	7
Socio-Environmental Criteria			1
CR = 0.01			

Table H.32: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 8

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	3	1/2	1/2	2	2	3	1/3
Material Weight		1	1/4	1/3	1/3	1/2	1/2	1/3
Fire Resistance			1	2	3	2	2	2
Thermal Performance				1	1/2	2	2	1/3
Acoustical Performance					1	2	1/2	1/3
Water Tightness						1	1/2	1/3
Air Tightness							1	1/3
Simplicity of Design Details								1
CR = 0.07								

Table H.33: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 8

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	2	1/2	1/2	2	1/2	1/2
Ease of Construction		1	1/2	1/2	2	1/2	1/2
Initial Cost			1	2	2	1/2	1/2
Maintenance Cost				1	1/2	2	1/2
Durability (expected service life)					1	1/3	1/2
Maintainability						1	1/2
Availability of Materials from Local Suppliers							1
CR = 0.09							

Table H.34: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 8

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/2	1/4	1/3	1/2	1/3	1/3	1/2
Control of Light		1	1/4	1/3	1/3	1/3	1/3	1/3
Safety During and after Construction			1	1/2	1/3	1/3	1/3	1/3
Disturbance of Community During Construction				1	1/2	1/2	1/2	1/3
Energy Consumption through Required Construction Equipment					1	1/2	2	1/2
Consumption of Materials						1	2	3
Waste Generation							1	1/2
Reusability/Recyclability of Materials								1
CR = 0.08								

Table H.35: Weight of criteria obtained from respondent No. 8

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.333	Wind Resistance	0.127	0.042
		Material Weight	0.043	0.014
		Fire Resistance	0.226	0.075
		Thermal Performance	0.121	0.040
		Acoustical Performance	0.099	0.033
		Water Tightness	0.064	0.021
		Air Tightness	0.092	0.031
		Simplicity of Design Details	0.228	0.076
		Total	1.000	0.333
Economic Criteria	0.592	Erection Time	0.107	0.063
		Ease of Construction	0.089	0.053
		Initial Cost	0.159	0.094
		Maintenance Cost	0.146	0.086
		Durability (expected service life)	0.095	0.056
		Maintainability	0.175	0.104
		Availability of Materials from Local Suppliers	0.229	0.136
		Total	1.000	0.592
Socio-Environmental Criteria	0.075	Aesthetics	0.048	0.004
		Control of Light	0.050	0.004
		Safety During and after Construction	0.087	0.007
		Disturbance of Community During Construction	0.101	0.008
		Energy Consumption through Required Construction Equipment	0.152	0.011
		Consumption of Materials	0.241	0.018
		Waste Generation	0.134	0.010
		Reusability/Recyclability of materials	0.187	0.014
Total	1.000	Total	1.000	0.075

H.8 Consistent results obtained from respondent No. 9

Table H.36: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 9

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	4	3
Economic Criteria		1	1/3
Socio-Environmental Criteria			1
CR = 0.07			

Table H.37: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 9

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	5	1/3	2	4	2	2	6
Material Weight		1	1/8	1/6	1/4	1/4	1/4	1/2
Fire Resistance			1	7	7	5	4	8
Thermal Performance				1	2	1/2	1/2	1/2
Acoustical Performance					1	1/5	1/5	1/3
Water Tightness						1	2	4
Air Tightness							1	4
Simplicity of Design Details								1
CR = 0.08								

Table H.38: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 9

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	2	1/2	1/2	4	2	1/2
Ease of Construction		1	1/2	1/2	2	2	1/2
Initial Cost			1	2	2	2	3
Maintenance Cost				1	1/2	2	1/2
Durability (expected service life)					1	1	1/2
Maintainability						1	1/2
Availability of Materials from Local Suppliers							1
CR = 0.09							

Table H.39: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 9

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/2	1/7	2	1/2	2	1/2	1/2
Control of Light		1	1/2	2	2	2	2	1/2
Safety During and after Construction			1	2	2	2	2	2
Disturbance of Community During Construction				1	1/2	1/2	1/2	1/2
Energy Consumption through Required Construction Equipment					1	1/2	2	1/2
Consumption of Materials						1	2	1/2
Waste Generation							1	1/2
Reusability/Recyclability of Materials								1
CR = 0.07								

Table H.40: Weight of criteria obtained from respondent No. 9

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.614	Wind Resistance	0.176	0.108
		Material Weight	0.025	0.015
		Fire Resistance	0.389	0.239
		Thermal Performance	0.067	0.041
		Acoustical Performance	0.038	0.023
		Water Tightness	0.134	0.082
		Air Tightness	0.115	0.071
		Simplicity of Design Details	0.056	0.034
		Total	1.000	0.614
Economic Criteria	0.117	Erection Time	0.153	0.018
		Ease of Construction	0.105	0.012
		Initial Cost	0.249	0.029
		Maintenance Cost	0.138	0.016
		Durability (expected service life)	0.097	0.011
		Maintainability	0.076	0.009
		Availability of Materials from Local Suppliers	0.181	0.021
		Total	0.999	0.117
Socio-Environmental Criteria	0.268	Aesthetics	0.081	0.022
		Control of Light	0.142	0.038
		Safety During and after Construction	0.249	0.067
		Disturbance of Community During Construction	0.061	0.016
		Energy Consumption through Required Construction Equipment	0.103	0.028
		Consumption of Materials	0.107	0.029
		Waste Generation	0.087	0.023
		Reusability/Recyclability of materials	0.168	0.045
Total	0.999	Total	0.998	0.267

H.9 Consistent results obtained from respondent No. 10

Table H.41: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 10

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	3	4
Economic Criteria		1	3
Socio-Environmental Criteria			1
CR = 0.07			

Table H.42: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 10

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	5	5	3	3	2	2	2
Material Weight		1	1/4	1/3	1/3	1/2	1/2	1/2
Fire Resistance			1	4	4	2	2	2
Thermal Performance				1	3	2	2	2
Acoustical Performance					1	1/2	1/2	2
Water Tightness						1	2	2
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.08								

Table H.43: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 10

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1	1/2	1/2	1/3	1/3	2
Ease of Construction		1	1/2	1/2	1/3	1/3	3
Initial Cost			1	2	3	3	3
Maintenance Cost				1	2	2	2
Durability (expected service life)					1	2	2
Maintainability						1	2
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table H.44: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 10

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	2	1/3	2	1/2	2	2	2
Control of Light		1	1/3	2	3	1/2	1/2	2
Safety During and after Construction			1	3	2	3	3	3
Disturbance of Community During Construction				1	1/2	1/3	1/2	1/2
Energy Consumption through Required Construction Equipment					1	2	2	2
Consumption of Materials						1	2	2
Waste Generation							1	2
Reusability/Recyclability of Materials								1
CR = 0.08								

Table H.45: Weight of criteria obtained from respondent No. 10

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.614	Wind Resistance	0.296	0.182
		Material Weight	0.039	0.024
		Fire Resistance	0.198	0.122
		Thermal Performance	0.129	0.079
		Acoustical Performance	0.070	0.043
		Water Tightness	0.108	0.066
		Air Tightness	0.092	0.056
		Simplicity of Design Details	0.067	0.041
		Total	0.999	0.613
Economic Criteria	0.268	Erection Time	0.083	0.022
		Ease of Construction	0.091	0.024
		Initial Cost	0.275	0.074
		Maintenance Cost	0.184	0.049
		Durability (expected service life)	0.167	0.045
		Maintainability	0.138	0.037
		Availability of Materials from Local Suppliers	0.062	0.017
		Total	1.000	0.268
Socio-Environmental Criteria	0.117	Aesthetics	0.137	0.016
		Control of Light	0.119	0.014
		Safety During and after Construction	0.264	0.031
		Disturbance of Community During Construction	0.052	0.006
		Energy Consumption through Required Construction Equipment	0.143	0.017
		Consumption of Materials	0.122	0.014
		Waste Generation	0.098	0.011
		Reusability/Recyclability of materials	0.064	0.007
Total	0.999	Total	0.999	0.117

H.10 Consistent results obtained from respondent No. 11

Table H.46: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 11

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	1	5
Economic Criteria		1	4
Socio-Environmental Criteria			1
CR = 0.01			

Table H.47: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 11

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	2	1/2	1/2	2	1/2	2	2
Material Weight		1	1/2	2	1/2	1/2	2	1/2
Fire Resistance			1	2	2	2	3	3
Thermal Performance				1	2	1/2	3	3
Acoustical Performance					1	1/2	1/2	2
Water Tightness						1	2	2
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.08								

Table H.48: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 11

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1/2	1/3	3	1/2	1/2	1/2
Ease of Construction		1	1/2	2	1/2	1/2	2
Initial Cost			1	1	1	1	2
Maintenance Cost				1	1	1	1/2
Durability (expected service life)					1	1	2
Maintainability						1	2
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table H.49: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 11

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/4	2	3	1/2	2	1/2	1/3
Control of Light		1	3	3	3	3	3	3
Safety During and after Construction			1	1	1	1/2	1/2	1/2
Disturbance of Community During Construction				1	1/4	1/3	1/4	1/4
Energy Consumption through Required Construction Equipment					1	1/3	1/3	1
Consumption of Materials						1	1	1
Waste Generation							1	1
Reusability/Recyclability of Materials								1
CR = 0.07								

Table H.50: Weight of criteria obtained from respondent No. 11

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.466	Wind Resistance	0.122	0.057
		Material Weight	0.101	0.047
		Fire Resistance	0.219	0.102
		Thermal Performance	0.144	0.067
		Acoustical Performance	0.091	0.042
		Water Tightness	0.170	0.079
		Air Tightness	0.082	0.038
		Simplicity of Design Details	0.071	0.033
		Total	1.000	0.466
Economic Criteria	0.433	Erection Time	0.102	0.044
		Ease of Construction	0.137	0.059
		Initial Cost	0.190	0.082
		Maintenance Cost	0.105	0.045
		Durability (expected service life)	0.176	0.076
		Maintainability	0.176	0.076
		Availability of Materials from Local Suppliers	0.113	0.049
		Total	0.999	0.433
Socio-Environmental Criteria	0.100	Aesthetics	0.097	0.010
		Control of Light	0.289	0.029
		Safety During and after Construction	0.063	0.006
		Disturbance of Community During Construction	0.043	0.004
		Energy Consumption through Required Construction Equipment	0.097	0.010
		Consumption of Materials	0.126	0.013
		Waste Generation	0.148	0.015
		Reusability/Recyclability of materials	0.137	0.014
Total	0.999	Total	1.000	0.100

H.11 Consistent results obtained from respondent No. 12

Table H.51: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 12

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	2	2
Economic Criteria		1	2
Socio-Environmental Criteria			1
CR = 0.05			

Table H.52: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 12

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	5	1	1	1	1	1	9
Material Weight		1	1/2	1/2	1/2	1/2	1/2	1
Fire Resistance			1	5	5	5	5	5
Thermal Performance				1	1	1	1	5
Acoustical Performance					1	1	1	5
Water Tightness						1	1	5
Air Tightness							1	5
Simplicity of Design Details								1
CR = 0.07								

Table H.53: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 12

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1/2	1/2	1/2	1/3	1/3	1/4
Ease of Construction		1	1/3	1/3	1/3	1/3	1/4
Initial Cost			1	1	1/3	1/3	1/4
Maintenance Cost				1	2	2	1/4
Durability (expected service life)					1	1	1/4
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.08							

Table H.54: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 12

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1	1/5	5	5	5	5	5
Control of Light		1	1/5	5	5	5	5	5
Safety During and after Construction			1	9	9	9	9	9
Disturbance of Community During Construction				1	1/2	1/2	1/2	2
Energy Consumption through Required Construction Equipment					1	1	1/2	1/2
Consumption of Materials						1	1	1
Waste Generation							1	2
Reusability/Recyclability of Materials								1
CR = 0.05								

Table H.55: Weight of criteria obtained from respondent No. 12

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.493	Wind Resistance	0.168	0.083
		Material Weight	0.057	0.028
		Fire Resistance	0.327	0.161
		Thermal Performance	0.105	0.052
		Acoustical Performance	0.105	0.052
		Water Tightness	0.105	0.052
		Air Tightness	0.105	0.052
		Simplicity of Design Details	0.029	0.014
		Total	1.001	0.493
Economic Criteria	0.311	Erection Time	0.051	0.016
		Ease of Construction	0.056	0.017
		Initial Cost	0.093	0.029
		Maintenance Cost	0.161	0.050
		Durability (expected service life)	0.140	0.044
		Maintainability	0.172	0.053
		Availability of Materials from Local Suppliers	0.327	0.102
		Total	1.000	0.311
Socio-Environmental Criteria	0.196	Aesthetics	0.168	0.033
		Control of Light	0.168	0.033
		Safety During and after Construction	0.464	0.091
		Disturbance of Community During Construction	0.034	0.007
		Energy Consumption through Required Construction Equipment	0.036	0.007
		Consumption of Materials	0.042	0.008
		Waste Generation	0.050	0.010
		Reusability/Recyclability of materials	0.037	0.007
Total	1.000	Total	0.999	0.196

H.12 Consistent results obtained from respondent No. 13

Table H.56: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 13

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	2	2
Economic Criteria		1	1/2
Socio-Environmental Criteria			1
CR = 0.05			

Table H.57: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 13

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	3	1/2	1	1	2	1	3
Material Weight		1	1/3	1/3	1/2	1/2	1/2	1/2
Fire Resistance			1	1	2	2	2	3
Thermal Performance				1	2	2	2	3
Acoustical Performance					1	1	2	2
Water Tightness						1	1	2
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.02								

Table H.58: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 13

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1/2	2	1/3	1/3	1/3	1/2
Ease of Construction		1	2	1	1/2	1/2	1/2
Initial Cost			1	1/2	1/2	1/2	1/2
Maintenance Cost				1	1	1	2
Durability (expected service life)					1	1	2
Maintainability						1	2
Availability of Materials from Local Suppliers							1
CR = 0.03							

Table H.59: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 13

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/2	1/2	2	2	2	3	1
Control of Light		1	1/2	2	2	2	3	1/2
Safety During and after Construction			1	3	2	3	3	1
Disturbance of Community During Construction				1	1	1	1	1/3
Energy Consumption through Required Construction Equipment					1	1	1	1/3
Consumption of Materials						1	1	1/3
Waste Generation							1	1/3
Reusability/Recyclability of Materials								1
CR = 0.02								

Table H.60: Weight of criteria obtained from respondent No. 13

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.493	Wind Resistance	0.150	0.074
		Material Weight	0.053	0.026
		Fire Resistance	0.210	0.104
		Thermal Performance	0.191	0.094
		Acoustical Performance	0.125	0.062
		Water Tightness	0.103	0.051
		Air Tightness	0.104	0.051
		Simplicity of Design Details	0.064	0.032
		Total	1.000	0.493
Economic Criteria	0.196	Erection Time	0.076	0.015
		Ease of Construction	0.121	0.024
		Initial Cost	0.074	0.015
		Maintenance Cost	0.187	0.037
		Durability (expected service life)	0.204	0.040
		Maintainability	0.204	0.040
		Availability of Materials from Local Suppliers	0.134	0.026
		Total	1.000	0.196
Socio-Environmental Criteria	0.311	Aesthetics	0.141	0.044
		Control of Light	0.155	0.048
		Safety During and after Construction	0.218	0.068
		Disturbance of Community During Construction	0.069	0.021
		Energy Consumption through Required Construction Equipment	0.074	0.023
		Consumption of Materials	0.069	0.021
		Waste Generation	0.063	0.020
		Reusability/Recyclability of materials	0.209	0.065
Total	1.000	Total	0.998	0.310

H.13 Consistent results obtained from respondent No. 14

Table H.61: Consistent pairwise comparison matrix of major criteria group evaluated by respondent No. 14

	Technical Criteria	Economic Criteria	Socio-Environmental Criteria
Technical Criteria	1	2	1/2
Economic Criteria		1	1/2
Socio-Environmental Criteria			1
CR = 0.05			

Table H.62: Consistent pairwise comparison matrix of technical criteria evaluated by respondent No. 14

	Wind resistance	Material Weight	Fire Resistance	Thermal Performance	Acoustical Performance	Water Tightness	Air Tightness	Simplicity of Design Details
Wind resistance	1	2	1/3	1	3	1	2	2
Material Weight		1	1/4	1/3	1/2	1/3	1/2	2
Fire Resistance			1	3	2	2	3	4
Thermal Performance				1	3	3	3	2
Acoustical Performance					1	1/3	1/2	3
Water Tightness						1	3	4
Air Tightness							1	2
Simplicity of Design Details								1
CR = 0.07								

Table H.63: Consistent pairwise comparison matrix of economic criteria evaluated by respondent No. 14

	Erection Time	Ease of Construction	Initial Cost	Maintenance Cost	Durability (expected service life)	Maintainability	Availability of Materials from Local Suppliers
Erection Time	1	1/2	1/4	1/4	1/4	1/3	1/3
Ease of Construction		1	1/2	1/3	1/4	1/3	1/3
Initial Cost			1	1/4	1/3	1/3	1
Maintenance Cost				1	1/2	1	1/2
Durability (expected service life)					1	2	2
Maintainability						1	1
Availability of Materials from Local Suppliers							1
CR = 0.05							

Table H.64: Consistent pairwise comparison matrix of socio-environmental criteria evaluated by respondent No. 14

	Aesthetics	Control of Light	Safety During and after Construction	Disturbance of Community During Construction	Energy Consumption through Required Construction Equipment	Consumption of Materials	Waste Generation	Reusability/Recyclability of Materials
Aesthetics	1	1/2	1/5	2	1	1/2	1/3	2
Control of Light		1	1/4	1	2	2	2	2
Safety During and after Construction			1	3	3	3	2	2
Disturbance of Community During Construction				1	2	1/2	1/2	2
Energy Consumption through Required Construction Equipment					1	1	1/2	2
Consumption of Materials						1	1/2	1/2
Waste Generation							1	2
Reusability/Recyclability of Materials								1
CR = 0.08								

Table H.65: Weight of criteria obtained from respondent No. 14

Category	Weight	Criteria	Local Weight	Global Weight
Technical Criteria	0.311	Wind Resistance	0.134	0.042
		Material Weight	0.055	0.017
		Fire Resistance	0.270	0.084
		Thermal Performance	0.185	0.058
		Acoustical Performance	0.076	0.024
		Water Tightness	0.151	0.047
		Air Tightness	0.082	0.026
		Simplicity of Design Details	0.047	0.015
		Total	1.000	0.311
Economic Criteria	0.196	Erection Time	0.044	0.009
		Ease of Construction	0.059	0.012
		Initial Cost	0.102	0.020
		Maintenance Cost	0.180	0.035
		Durability (expected service life)	0.274	0.054
		Maintainability	0.172	0.034
		Availability of Materials from Local Suppliers	0.168	0.033
		Total	0.999	0.196
Socio-Environmental Criteria	0.493	Aesthetics	0.083	0.041
		Control of Light	0.144	0.071
		Safety During and after Construction	0.287	0.141
		Disturbance of Community During Construction	0.092	0.045
		Energy Consumption through Required Construction Equipment	0.079	0.039
		Consumption of Materials	0.091	0.045
		Waste Generation	0.147	0.072
		Reusability/Recyclability of materials	0.077	0.038
Total	1.000	Total	1.000	0.493

APPENDIX I: APPLICATION VIEW CODE

```
<head>
<script src="tablesorter.js"></script>
</head>

<div class="container">
<div class="jumbotron jumbotron-fluid">
<div class="container">
<div class="row">
<div class="col-md-3">

</div>
<div class="col-md-9">
<h3>AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings</h3>
<h4>King Fahd University of Petroleum and Minerals</h4>
<h5>Department of Construction Engineering and Management</h5>
<h6>College of Environmental Design</h6>
<br>
<p id="description">This model is developed to facilitate the process of evaluating, ranking, and selecting curtain wall systems used in office buildings located in Saudi Arabia</p>
</div>
</div>
</div>
</div>

<div *ngIf="!hideInouts">
<div class="form-group">
<label for="projectName">Project Name</label>
<input type="text" class="form-control" id="projectName" [(ngModel)] = "projectName">
</div>
<div class="form-group">
<label for="province">Select Region</label>
<select class="form-control" id="province" [(ngModel)]="region">
<option>Al-Riyadh</option>
<option>Eastern Province</option>
```

```

    <option>Makkah Al-Mokarramah</option>
    <option>Aseer</option>
    <option>Al-Qaseem</option>
    <option>Northern Borders</option>
    <option>Al-Madinah Al-Monawarah</option>
    <option>Hail</option>
    <option>Tabuk</option>
    <option>Jazan</option>
    <option>Al-Jowf</option>
    <option>Najran</option>
    <option>Al-Baha</option>
  </select>
</div>
<div class="form-group" *ngIf="region == 'Eastern Province'">
  <label for="city">Select City</label>
  <select class="form-control" id="city" [(ngModel)]="city">
    <option>Dammam</option>
    <option>Jubail</option>
    <option>Khobar</option>
    <option>Dhahran</option>
    <option>Qatif</option>
    <option>Khafji</option>
    <option>Nuayriyah</option>
    <option>Ras Tanura</option>
  </select>
</div>
<div class="form-group">
  <label for="numberOfWalls">Number of wall alternatives to be evaluated</label>
  <input type="number" class="form-control" id="numberOfWalls" max="6" min="1"
[(ngModel)]="numberOfWalls" >
  <p class = "hint">*Number between 0 and 6</p>
</div>

<div class="form-group">
  <button type="button" class="btn btn-sm btn-primary" (click) =
"openHelpDialog()">Help</button>
</div>

<!-- -->

<table class="table" id="dtBasicExample">
  <thead>
    <tr>
      <th scope="col">Criteria / Wall Alternatives</th>

```

```

<th scope="col">
  <div class="form-group" *ngIf="numberOfWalls >= 1">
    <select class="form-control" id="wall1" [(ngModel)]="wall1Option"
#wall1Select (change) = "onChangeWall1(wall1Option)">
      <option>Precast Concrete Cladding Panels</option>
      <option>Unitized Systems</option>
      <option>Column-Cover and Spandrel Systems</option>
      <option>Unit-and-Mullion Systems</option>
      <option>Stick Systems</option>
      <option>Point-Supported Glazing Systems (Spider System)</option>
      <option>Other</option>
    </select>
    <input class="form-control" type="text" [(ngModel)]="otherWall1"
*ngIf="other1">
  </div>
</th>
<th scope="col">
  <div class="form-group" *ngIf="numberOfWalls >= 2">
    <select class="form-control" id="wall2" [(ngModel)]="wall2Option"
#wall2Select (change) = "onChangeWall2(wall2Option)">
      <option>Precast Concrete Cladding Panels</option>
      <option>Unitized Systems</option>
      <option>Column-Cover and Spandrel Systems</option>
      <option>Unit-and-Mullion Systems</option>
      <option>Stick Systems</option>
      <option>Point-Supported Glazing Systems (Spider System)</option>
      <option>Other</option>
    </select>
    <input class="form-control" type="text" [(ngModel)]="otherWall2"
*ngIf="other2">
  </div>
</th>
<th scope="col">
  <div class="form-group" *ngIf="numberOfWalls >= 3">
    <select class="form-control" id="wall3" [(ngModel)]="wall3Option"
#wall3Select (change) = "onChangeWall3(wall3Option)">
      <option>Precast Concrete Cladding Panels</option>
      <option>Unitized Systems</option>
      <option>Column-Cover and Spandrel Systems</option>
      <option>Unit-and-Mullion Systems</option>
      <option>Stick Systems</option>
      <option>Point-Supported Glazing Systems (Spider System)</option>
      <option>Other</option>
    </select>

```

```

        <input class="form-control" type="text" [(ngModel)]="otherWall3"
*ngIf="other3">
    </div>
</th>
<th scope="col">
    <div class="form-group" *ngIf="numberOfWalls >= 4">
        <select class="form-control" id="wall4" [(ngModel)]="wall4Option"
#wall4Select (change) = "onChangeWall4(wall4Option)">
            <option>Precast Concrete Cladding Panels</option>
            <option>Unitized Systems</option>
            <option>Column-Cover and Spandrel Systems</option>
            <option>Unit-and-Mullion Systems</option>
            <option>Stick Systems</option>
            <option>Point-Supported Glazing Systems (Spider System)</option>
            <option>Other</option>
        </select>
        <input class="form-control" type="text" [(ngModel)]="otherWall4"
*ngIf="other4">
    </div>
</th>
<th scope="col">
    <div class="form-group" *ngIf="numberOfWalls >= 5">
        <select class="form-control" id="wall5" [(ngModel)]="wall5Option"
#wall5Select (change) = "onChangeWall5(wall5Option)">
            <option>Precast Concrete Cladding Panels</option>
            <option>Unitized Systems</option>
            <option>Column-Cover and Spandrel Systems</option>
            <option>Unit-and-Mullion Systems</option>
            <option>Stick Systems</option>
            <option>Point-Supported Glazing Systems (Spider System)</option>
            <option>Other</option>
        </select>
        <input class="form-control" type="text" [(ngModel)]="otherWall5"
*ngIf="other5">
    </div>
</th>
<th scope="col">
    <div class="form-group" *ngIf="numberOfWalls >= 6">
        <select class="form-control" id="wall6" [(ngModel)]="wall6Option"
#wall6Select (change) = "onChangeWall6(wall6Option)">
            <option>Precast Concrete Cladding Panels</option>
            <option>Unitized Systems</option>
            <option>Column-Cover and Spandrel Systems</option>
            <option>Unit-and-Mullion Systems</option>

```

```

        <option>Stick Systems</option>
        <option>Point-Supported Glazing Systems (Spider System)</option>
        <option>Other</option>
    </select>
    <input class="form-control" type="text" [(ngModel)]="otherWall6"
*ngIf="other6">
        </div>
    </th>
</tr>
</thead>
<tbody>
    <tr>
        <th>Technical Criteria</th>
    </tr>
    <tr>
        <td>Wind Resistance</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c1"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c1"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c1"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c1"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c1"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c1"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Material Weight</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c2"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c2"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c2"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c2"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c2"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c2"
*ngIf="numberOfWalls >= 6"></td>
    </tr>

```

```

        <tr>
            <td>Fire Resistance</td>
            <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c3"
*ngIf="numberOfWalls >= 1"></td>
            <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c3"
*ngIf="numberOfWalls >= 2"></td>
            <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c3"
*ngIf="numberOfWalls >= 3"></td>
            <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c3"
*ngIf="numberOfWalls >= 4"></td>
            <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c3"
*ngIf="numberOfWalls >= 5"></td>
            <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c3"
*ngIf="numberOfWalls >= 6"></td>
        </tr>
        <tr>
            <td>Thermal Performance</td>
            <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c4"
*ngIf="numberOfWalls >= 1"></td>
            <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c4"
*ngIf="numberOfWalls >= 2"></td>
            <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c4"
*ngIf="numberOfWalls >= 3"></td>
            <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c4"
*ngIf="numberOfWalls >= 4"></td>
            <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c4"
*ngIf="numberOfWalls >= 5"></td>
            <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c4"
*ngIf="numberOfWalls >= 6"></td>
        </tr>
        <tr>
            <td>Acoustical Performance</td>
            <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c5"
*ngIf="numberOfWalls >= 1"></td>
            <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c5"
*ngIf="numberOfWalls >= 2"></td>
            <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c5"
*ngIf="numberOfWalls >= 3"></td>
            <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c5"
*ngIf="numberOfWalls >= 4"></td>
            <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c5"
*ngIf="numberOfWalls >= 5"></td>
            <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c5"
*ngIf="numberOfWalls >= 6"></td>

```

```

</tr>
<tr>
  <td>Water Tightness</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c6"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c6"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c6"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c6"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c6"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c6"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Air Tightness</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c7"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c7"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c7"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c7"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c7"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c7"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Simplicity of Design Details</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c8"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c8"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c8"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c8"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c8"
*ngIf="numberOfWalls >= 5"></td>

```

```

        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c8"
*ngIf="numberOfWalls >= 6"></td>        </tr>

    <tr>
        <th>Economic Criteria</th>
    </tr>

    <tr>
        <td>Erection Time</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c9"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c9"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c9"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c9"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c9"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c9"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Ease of Construction </td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c10"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c10"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c10"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c10"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c10"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c10"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Initial Cost</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c11"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c11"
*ngIf="numberOfWalls >= 2"></td>

```

```

        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c11"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c11"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c11"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c11"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Maintenance Cost</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c12"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c12"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c12"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c12"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c12"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c12"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Durability (expected service life)</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c13"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c13"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c13"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c13"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c13"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c13"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Maintainability</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c14"
*ngIf="numberOfWalls >= 1"></td>

```

```

        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c14"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c14"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c14"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c14"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c14"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <td>Availability of Materials from Local Suppliers</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c15"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c15"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c15"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c15"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c15"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c15"
*ngIf="numberOfWalls >= 6"></td>
    </tr>
    <tr>
        <th>Socio-environmental Criteria</th>
    </tr>
    <tr>
        <td>Aesthetics</td>
        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c16"
*ngIf="numberOfWalls >= 1"></td>
        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c16"
*ngIf="numberOfWalls >= 2"></td>
        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c16"
*ngIf="numberOfWalls >= 3"></td>
        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c16"
*ngIf="numberOfWalls >= 4"></td>
        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c16"
*ngIf="numberOfWalls >= 5"></td>
        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c16"
*ngIf="numberOfWalls >= 6"></td>
    </tr>

```

```

<tr>
  <td>Control of Light</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c17"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c17"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c17"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c17"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c17"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c17"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Safety During and after Construction</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c18"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c18"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c18"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c18"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c18"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c18"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Disturbance of Community During Construction</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c19"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c19"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c19"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c19"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c19"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c19"
*ngIf="numberOfWalls >= 6"></td>

```

```

</tr>
<tr>
  <td>Energy Consumption through Required Construction Equipment</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c20"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c20"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c20"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c20"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c20"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c20"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Consumption of Materials</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c21"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c21"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c21"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c21"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c21"
*ngIf="numberOfWalls >= 5"></td>
  <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]=w6_c21"
*ngIf="numberOfWalls >= 6"></td>
</tr>
<tr>
  <td>Waste Generation</td>
  <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]=w1_c22"
*ngIf="numberOfWalls >= 1"></td>
  <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]=w2_c22"
*ngIf="numberOfWalls >= 2"></td>
  <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]=w3_c22"
*ngIf="numberOfWalls >= 3"></td>
  <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]=w4_c22"
*ngIf="numberOfWalls >= 4"></td>
  <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]=w5_c22"
*ngIf="numberOfWalls >= 5"></td>

```

```

        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c22"
*ngIf="numberOfWalls >= 6"></td>

```

```

    </tr>

```

```

    <tr>

```

```

        <td>Reusability/Recyclability of materials</td>

```

```

        <td><input type="number" class="form-control" id="w1_c1" [(ngModel)]="w1_c23"
*ngIf="numberOfWalls >= 1"></td>

```

```

        <td><input type="number" class="form-control" id="w2_c1" [(ngModel)]="w2_c23"
*ngIf="numberOfWalls >= 2"></td>

```

```

        <td><input type="number" class="form-control" id="w3_c1" [(ngModel)]="w3_c23"
*ngIf="numberOfWalls >= 3"></td>

```

```

        <td><input type="number" class="form-control" id="w4_c1" [(ngModel)]="w4_c23"
*ngIf="numberOfWalls >= 4"></td>

```

```

        <td><input type="number" class="form-control" id="w5_c1" [(ngModel)]="w5_c23"
*ngIf="numberOfWalls >= 5"></td>

```

```

        <td><input type="number" class="form-control" id="w6_c1" [(ngModel)]="w6_c23"
*ngIf="numberOfWalls >= 6"></td>

```

```

    </tr>

```

```

</tbody>

```

```

</table>

```

```

<div class="form-group">

```

```

    <button type="button" class="btn btn-lg btn-primary" (click) = calc() >Show
Results</button>

```

```

</div>

```

```

</div>

```

```

<!-- -->

```

```

<div *ngIf="showResults">

```

```

    <table class="table table-dark">

```

```

        <tr>

```

```

            <th>Project Name: {{projectName}}</th>

```

```

            <th>Region: {{region}}</th>

```

```

            <th *ngIf="region == 'Eastern Province'">City: {{city}}</th>

```

```

        </tr>

```

```

    </table>

```

```

<div class="form-group">

```

```

    <button class="btn btn-md btn-success" (click) = "sortTable()">Sort</button>

```

```

</div>

```

```

<table class="table table-dark" id="myTable">

```

```

    <thead>

```

```

<tr>
  <th scope="col">Curtain Wall Alternatives</th>
  <th scope="col">Total</th>
</tr>
</thead>
<tbody>
  <tr *ngIf="numberOfWalls >= 1">
    <th scope="row" *ngIf='wall1Option != "Other"'>{{wall1Option}}</th>
    <th scope="row" *ngIf="other1">{{otherWall1}}</th>
    <td>{{w1Total}}</td>
  </tr>
  <tr *ngIf="numberOfWalls >= 2">
    <th scope="row" *ngIf='wall2Option != "Other"'>{{wall2Option}}</th>
    <th scope="row" *ngIf="other2">{{otherWall2}}</th>
    <td>{{w2Total}}</td>
  </tr>
  <tr *ngIf="numberOfWalls >= 3">
    <th scope="row" *ngIf='wall3Option != "Other"'>{{wall3Option}}</th>
    <th scope="row" *ngIf="other3">{{otherWall3}}</th>
    <td>{{w3Total}}</td>
  </tr>

  <tr *ngIf="numberOfWalls >= 4">
    <th scope="row" *ngIf='wall4Option != "Other"'>{{wall4Option}}</th>
    <th scope="row" *ngIf="other4">{{otherWall4}}</th>
    <td>{{w4Total}}</td>
  </tr>
  <tr *ngIf="numberOfWalls >= 5">
    <th scope="row" *ngIf='wall5Option != "Other"'>{{wall5Option}}</th>
    <th scope="row" *ngIf="other5">{{otherWall5}}</th>
    <td>{{w5Total}}</td>
  </tr>
  <tr *ngIf="numberOfWalls >= 6">
    <th scope="row" *ngIf='wall6Option != "Other"'>{{wall6Option}}</th>
    <th scope="row" *ngIf="other6">{{otherWall6}}</th>
    <td>{{w6Total}}</td>
  </tr>
</tbody>
</table>
</div>
</div>

```

APPENDIX J: VALIDATION FORM

AHP/MAUT-Based Model for Selecting Curtain Wall Systems in Office Buildings

Summary

Dear Sir,

The selection of curtain walls plays a vital role in the technical, economic, and socio-environmental aspects of office buildings and there are many alternatives of them which can be used. This study requires conducting interviews with experts in the field of curtain wall systems. The interview consists of the following parts: (1) filling general information of the interviewee, (2) selection of curtain wall systems that can be considered in an office building project, (3) evaluating the selected curtain wall systems with respect to different criteria, (4) identifying the most preferred system and providing the reason for that, and (5) entering the evaluation data to a computer application.

This study is conducted by a researcher in the Department of Construction Engineering and Management (CEM) at King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia. Therefore, all information obtained from the surveys is confidential and will be used for research purposes.

Best Regards,

Hamza Basel Hamida,

Construction Engineering and Management Department,

King Fahd University of Petroleum and Minerals,

Dhahran, Saudi Arabia

Email: g201215140@kfupm.edu.sa

Mobile phone: +966530217690

Part (1): General Information

1. Information of the Respondent (Optional)

Name	
Organization name	
Organization address	
Phone number	
Email address	

2. Technical Background of the Respondent

- ☐ Architecture
- ☐ Architectural/Building Engineering
- ☐ Civil/Construction Engineering
- ☐ Other (Please Specify) _____.

3. Years of Experience

- ☐ 5 years and less
- ☐ 5 to 10 years
- ☐ 10 to 20 years
- ☐ Over 20 years

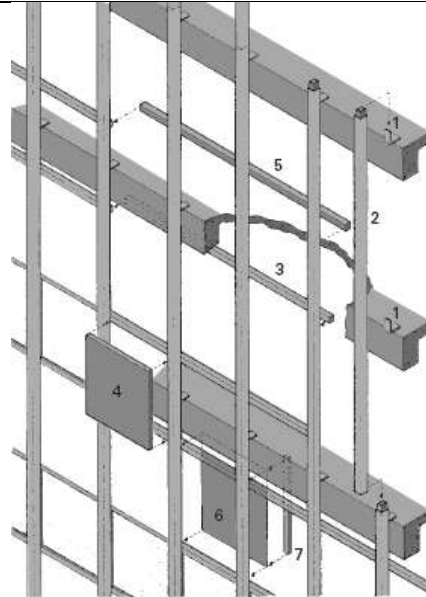
Part (2): Selection of Curtain Wall Systems

Kindly select the curtain wall alternatives you consider in an office building project located at Khobar city in the Eastern Province of Saudi Arabia

(A) The stick curtain wall system which consists of the following:

- (1) Anchors
- (2) Mullions
- (3) Horizontal rails
- (4) Spandrel panels
- (5) Horizontal rails
- (6) Vision glass
- (7) Interior mullion trim

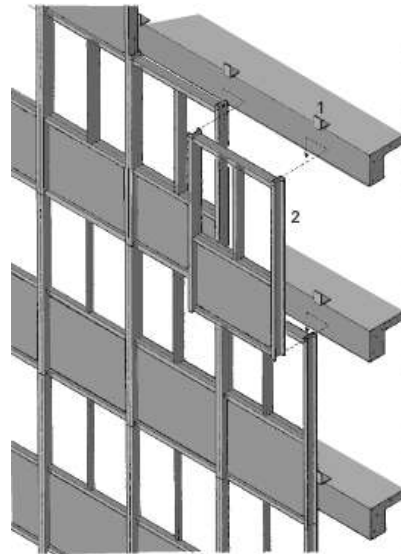
[]



(B) The unitized curtain wall system which consists of the following:

- (1) Anchors
- (2) Preassembled framed units

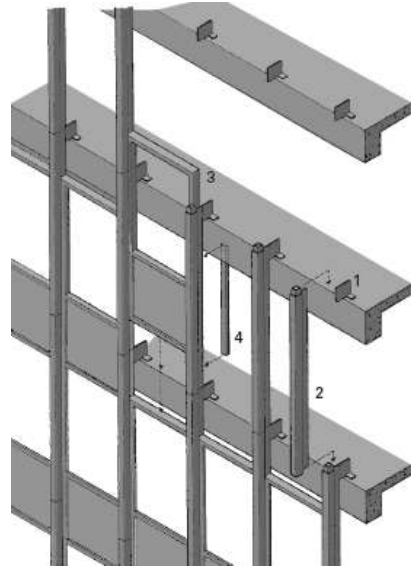
[]



(C) The unit-and-mullion curtain wall system which consists of the following:

- (1) Anchors
- (2) Mullions
- (3) Preassembled units
- (4) Interior mullion trim

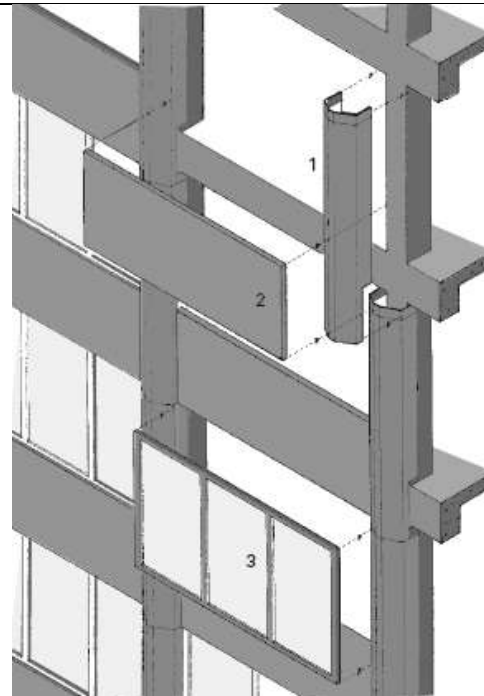
[]



(D) The column-cover and spandrel curtain wall system which consists of the following:

- (1) Column covers
- (2) Spandrel panels
- (3) Glazing units

[]



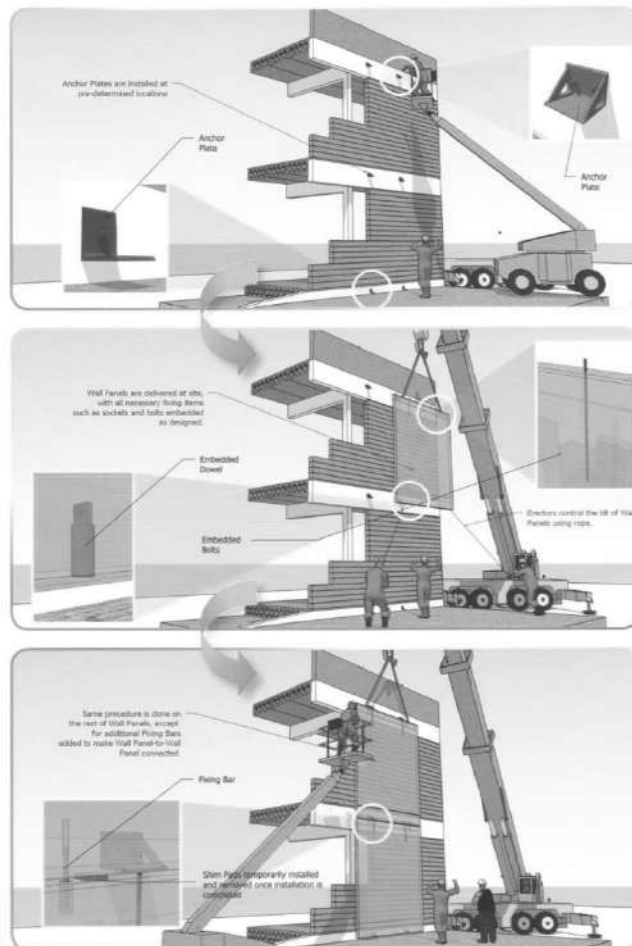
(E) The spiders fixed to building frames that are used in structural standoff systems (Spider System)

[]



(F) Precast concrete wall cladding

[]



Part (3): Evaluation of the Curtain Wall System

Kindly use the scale that ranges from 1 to 5 in the following table to evaluate the selected curtain wall systems with respect to different criteria.

Scale	Description
1	Not Preferred
2	Preferred Somewhat
3	Moderately Preferred
4	Very Preferred
5	Extremely Preferred

Category	Criteria	(A) Stick System	(B) Unitized System	(C) Unit-and-mullion System	(D) Column-cover and spandrel	(E) Point-Supported Glazing Systems (Spider System)	(F) Precast Concrete Cladding Panels
		[]	[]	[]	[]	[]	[]
Technical Criteria	Wind Resistance						
	Material Weight						
	Fire Resistance						
	Thermal Performance						
	Acoustical Performance						
	Water Tightness						
	Air Tightness						
	Simplicity of Design Details						
Economic Criteria	Erection Time						
	Ease of Construction						
	Initial Cost						
	Maintenance Cost						
	Durability (expected service life)						
	Maintainability						
	Availability of Materials from Local Suppliers						
Socio-Environmental Criteria	Aesthetics						
	Control of Light						
	Safety During and after Construction						
	Disturbance of Community During Construction						
	Energy Consumption through Required Construction Equipment						
	Consumption of Materials						
	Waste Generation						
	Reusability/Recyclability of materials						

Part (4): Identification of the most Preferred

Based on your experience and knowledge, kindly identify the most preferred system among the ones you selected and then provide the reason for that

Part (5): Computer Evaluation

Kindly enter the assigned scores in part 3 to the computer application

VITAE

Name : Hamza Basel Hamida

Date of Birth : 11/27/1994

Email : hamzahumaidah@gmail.com

Address : 2948, Anas Ibn Muadh Ibn Jabal Street, Doha Alshamaliah, 34249- 6712 Dhahran, Saudi Arabia

Academic Background : Master of Science (MS) in Construction Engineering and Management, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, March 2020.

Bachelor of Science (BS) in Civil Engineering (with Second Class Honors), King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, January 2018.

Research Interest : Artificial neural networks and cost estimation.

Sustainability and multi-criteria decision-making.

Selection of construction equipment.

Adoption of Building Information Modeling in construction projects.