

THE DIFFERENTIATED FUNCTIONS OF SKETCH AND DIGITAL
MODALITIES IN ARCHITECTURAL COLLABORATION DESIGN

DANFULANI BABANGIDA IDI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

SEPTEMBER 2018

This thesis is dedicated;

I wish to dedicate this thesis to the development of Humanity, to my beloved mother Hajia Amina Mallam Adamu and my late father Alhaji Idi Danfulani (May his soul rest in peace, Amin.) Mom, Dad I 'am so proud of you.

ACKNOWLEDGEMENT

All thanks due to Allah (Sub'hanahu Wata'alah) WHO create us, give us life, wisdom, strength, protection, guidance, and make it possible the successful completion of this program. I would also like to register my appreciation to my parent especially my late father Alhaji Idi Danfulani who have supported me throughout my life, but unfortunately could not see this day. Dad you are the best am proud of you, even in your absence my relations and others are still with all necessary support thank you dad. Then, to my mother Hajia Amina Mallam Adamu I aknowledge your love, care, advice and prayers. I have been blessed with wonderful family members such as my wife Fatima, Asmau'Lantana my daughter, my son Idris, bro Sani, bro Mohammed, bro Ali, sis Fatima, sis Hajara, sis Maryam to mention but a few thanks for all your support I love you all. I would also like to acknowledge my supervisor in person of Associate Professor Dr. Khairul Anwar Bin Mohammed Khaidzir for the courage, advice and guidance which helps me in understanding my research and gives me the opportunity to expand my views to pursue the research up to this stage. Thank you sir you will remain a role model in the rest of my life. I would like to acknowledge the staff of Universiti Teknologi Malaysia and School of Postgraduate Studies UTM for the services rendered to me from my first day and ever since please do keep it up your work is appreciated. During the process of undertaking this research it is my wish to acknowledge the following members of the Department of Architecture Faculty of the Built Environment Universiti Teknologi Malaysia like Safwan Saifuddin, Zheng Lin, Hoe Sieng, Faiz Toorabally, Ke, Hui, Noor Hidayat, Siti Nurliyana, Kher Choon, Zhao Wei, Boon Siand, Sze Wei, Lean Keat, Sai Fong, Pui Teng and Chong Keat, Badiru Yusuf, Umar Farooq, Liman Saba, Joshua Abimaje, Habu Abba, Dr Dodo, Associate Professor Dr. Rashid Embi, Associate Professor Dr. Mahamud Jusan, Prof Hamdan, Prof Hafeez, Prof Shafeeq, Prof Iskandar and Prof Rafee, I thank you all. For the non-academic staff I thank the management staff of Faculty of Built Environment Universiti Teknologi Malaysia like Facility department staff, Fazurah and Fizah, and Dr Atta Idrawani may almighty Allah reward you with Aljannatil Firdaus Khalidan Fiha Abadan. Finally what would research life be without friends the list is endless but cant fail to mention few like Khairil Halim, Yahaya Ahmed to mention but a few, your wonderful source of inspiration and company is appreciated. I thank you and god bless you all.

ABSTRACT

Architectural collaboration is seen by many as an essential strategy that produces an outcome that is beyond individual vision. The majority of literature defines collaboration as two or more people sharing their differences constructively to search for a common goal. However, defining collaboration in the context of conceptual architectural design as two or more designers working together to achieve a common design goal appears to be very basic, as the definition does not in any way indicate how multiple designers can transform their tacit knowledge into an explicit building product. Instead, the definition undermines the rationale that collaboration can improve efficiency and effectiveness in sharing design ideas. This also implies that there is no clear understanding as to whether complex design activities such as actions, transformation, and reasoning can be readily circumscribed into collaborative settings. It presents one of the most significant challenges in realizing the much anticipated collaborative approach to design problem-solving. Therefore, there is a need to investigate key characteristics of collaboration in architectural design and their implications for the building development process. Thus this research aims to investigate the phenomenon of conceptual architectural collaboration design using the protocol study technique. The protocol consists of eight different design teams subjected to the usage of sketch modality to design a bus stand and a digital modality to design a commercial kiosk. A coding scheme based on design action, transformation, reasoning and knowledge transformation is employed to generate empirical data from the design protocol of the two modalities. Statistical analysis using Chi-Square cross tabulation has established a significant association between the two modalities and design activities. The results indicate that the design activities of the two modalities are statistically different concerning the distributed frequencies and duration of parameters of cognitive actions, tacit knowledge transformation, reasoning strategies and transformation. Higher framing action, abduction reasoning strategy and lateral transformation are not affected by the sketch modality but are affected by the change to the digital modality. Similarly, higher moving action, deduction reasoning strategy, and vertical transformation are not affected by the digital modality but are affected by the sketch modality. The correlation analysis of the sketch modality also established a significant relationship between parameters of tacit knowledge transformation, cognitive actions, reasoning strategies and design transformation. This findings provide answers to the types of modality that can influence or affect the process of socialization in the knowledge transformation during design collaboration. In conclusion, an integrated thinking pattern for conceptual architectural collaboration design is proposed.

ABSTRAK

Kerjasama dalam seni bina dilihat oleh kebanyakan pihak sebagai strategi penting dalam menghasilkan dapatan di luar kotak fikiran individu. Kebanyakan kajian literatur mentakrifkan kerjasama sebagai dua atau lebih pereka yang bekerja bersama-sama untuk mencapai matlamat reka bentuk yang sama. Walau bagaimanapun definisi itu tidak menunjukkan bagaimana beberapa pereka dapat mengubah pengetahuan tersirat mereka menjadi hasil rekabentuk bangunan yang khusus. Sebaliknya, definisi itu menjejaskan rasional bahawa kerjasama boleh meningkatkan kecekapan dan keberkesanan semasa berkongsi idea reka bentuk. Ini juga menunjukkan bahawa tidak ada pemahaman yang jelas tentang apakah aktiviti reka bentuk kompleks seperti tindakan, transformasi, dan penaakulan dapat dibendung dengan mudah ke dalam tetapan kolaborasi. Ia menyajikan salah satu cabaran yang paling penting dalam merealisasikan pendekatan kolaborasi yang diharapkan untuk penyelesaian masalah rekabentuk. Oleh itu, terdapat keperluan untuk mengkaji ciri utama kerjasama dalam reka bentuk seni bina dan implikasinya dalam proses pembangunan bangunan. Oleh itu, kajian ini bertujuan untuk mengkaji fenomena reka bentuk kerjasama seni bina konseptual menggunakan teknik kajian protokol. Protokol ini terbahagi kepada 8 pasukan reka bentuk yang berbeza yang tertakluk kepada penggunaan modaliti lakaran untuk mereka bentuk pondok bas dan modaliti digital untuk mereka bentuk kiosk komersil. Sistem kod berdasarkan tindakan reka bentuk, transformasi, penaakulan dan transformasi pengetahuan digunakan untuk menghasilkan data empirikal dari protokol reka bentuk dua modaliti ini. Analisis statistik menggunakan taburan 'Chi – Square' telah mengesahkan satu persamaan penting antara dua modaliti dan aktiviti reka bentuk ini. Hasil kajian menunjukkan bahawa aktiviti reka bentuk kedua modaliti ini adalah berbeza secara statistik mengenai frekuensi yang diedarkan dan tempoh parameter tindakan kognitif transformasi tacit, strategi penaakulan dan transformasi. Tindakan pembingkai yang lebih tinggi, strategi pemikiran dan transformasi sisi tidak dipengaruhi oleh modaliti lakaran tetapi dipengaruhi oleh perubahan kepada modaliti digital. Begitu juga, tindakan bergerak yang lebih tinggi, strategi penaakulan dan transformasi menegak tidak terjejas oleh modaliti digital tetapi dipengaruhi oleh modaliti lakaran. Analisis korelasi modaliti lakaran juga mengesahkan hubungan yang signifikan antara parameter transformasi pengetahuan tacit tindakan kognitif, strategi pemikiran dan transformasi reka bentuk. Dapatan ini memberi jawapan kepada hipotesis bahawa jenis modaliti boleh mempengaruhi atau menjejaskan proses sosialisasi dalam transformasi pengetahuan semasa kerjasama reka bentuk yang membawa kepada corak pemikiran bersepadu yang dicadangkan untuk reka bentuk kerjasama konseptual seni bina.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	vii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xvii
	LIST OF SYMBOLS	xxi
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Background to the Study	2
	1.3 Problem Statement	5
	1.4 Research Gap	6
	1.5 Research Aim	7
	1.6 Research Objectives	7
	1.7 Research Questions	7
	1.8 Research Significance	8

1.9	Research Framework	8
1.10	Research Methodology	10
1.11	Research Scope	11
1.12	Research Overview	11
1.13	Structure of Thesis	12
2	DESIGN	15
2.1	Introduction	15
2.2	Theoretical Views of Design	15
2.2.1	The Technical rational theory of design	16
2.2.2	Design Science Theory	17
2.2.3	Reflective Theory	17
2.3	Seeing design a process	18
2.3.1	Design as a concept and technical stages	19
2.3.2	Design as movement around phases	20
2.3.3	Design as assimilation, general study, development, and communication	21
2.3.4	Design as sequence of analysis, synthesis, appraisal, and decision	22
2.3.5	Design as a movement from overall problem to overall solution stages	23
2.4	Method of Analyzing design	25
2.4.1	Analyzing design through links	25
2.4.2	Analyzing design through the ontology of function behavior and structure	26
2.4.3	Analyzing design through thinking and actions	28
2.5	The Tacit nature of Design Knowledge	29
2.5.1	Tacit knowledge in design	30
2.5.2	Explicit knowledge of design	31

2.6	Critical Perspective of Conceptual architectural collaboration design based on Building Information Modelling (BIM) framework	31
2.6.1	Testing collaborative tools on Design	35
2.6.2	Exploring Virtual Collaboration Activities on Design.	36
2.6.3	Examining Collaborative environment on Design	40
2.6.4	Using Collaborative Media on Design	43
2.6.5	Evidence-Based collaboration in design	44
2.7	Summary	47
3	COLLABORATION IN DESIGN	51
3.1	Introduction	51
3.2	Theoretical framework of Collaboration in the Context of Design	51
3.2.1	Nature of architectural collaboration design	57
3.2.2	Shared design task	58
3.2.3	Shared Environment	60
3.2.4	The design team	65
3.2.5	Modalities of interaction	74
3.2.6	Tacit Knowledge Transformation	79
3.2.6.1	SECI Model of Tacit Knowledge Transformation	82
3.2.6.2	Source of Tacit knowledge	84
3.2.6.3	Tacit knowledge spaces	86
3.2.7	Cognitive action	88
3.2.8	Reasoning strategy	93
3.2.9	Visual Transformation in design	98
3.3	Summary	100
4	METHODOLOGY	103
4.1	Introduction	103

4.2	Phase 1 (Research Theoretical Set-up)	104
4.2.1	Research Philosophy	104
4.2.2	Research Approach	105
4.2.3	Mixed Research Methodology	106
4.3	Phase 2 (Research Techniques)	109
4.3.1	Video Observation	114
4.3.1.1	Video Observation Set-up	116
4.3.2	Research Design Quality Measurement Exercise	123
4.4	Phase 3 Data Analysis	125
4.4.1	Transcribing Protocol	125
4.4.2	Segmenting Protocol	129
4.4.3	Coding Protocol	129
4.4.3.1	Coding Validation	138
4.4.3.2	Tabulation	139
4.4.4	Analyzing Design Measurement	142
4.4.4.1	Design Measuring Sessions	142
4.4.4.2	Tabulation	144
4.4.5	SPSS Tests (non-parametric)	145
4.4.5.1	Objective 2: To Determine the Impact of Modalities on Conceptual architectural collaboration design	146
4.4.5.2	Objective 3: To Establish the Parameters of Tacit Knowledge Transformation in conceptual architectural collaboration design	146
4.4.5.3	Objective 4: To discover the relationship between performance and knowledge transformation in conceptual architectural collaboration design	146
4.4.6	Content Analysis (coding-sheets)	147
4.4.6.1	Objective 5: To Develop a Pattern for Conceptual architectural collaboration design	147

4.5	Summary	147
5	COLLABORATIVE CONSTRUCTS IN DESIGN	149
5.1	Introduction	149
5.2	Characteristics of Collaborative Construct in Design	149
5.2.1	Outline of Collaborative Construct in design	150
5.2.1.1	Transforming Knowledge from Tacit to Explicit	151
5.2.1.2	Cognitive Actions	154
5.2.1.3	Reasoning Strategies	155
5.3	Summary	158
6	RESULT AND DISCUSSION	159
6.1	Introduction	159
6.2	Type of Modality significantly influences the nature of conceptual architectural collaboration design.	159
6.3	Knowledge transformation is significantly related to conceptual architectural collaboration design.	162
6.4	Modality is significantly related to Productivity of knowledge transformation during conceptual architectural collaboration design.	164
6.5	Propose Patterns for Conceptual Architectural Collaboration Design	166
6.6	Summary	171
7	CONCLUSION	173
7.1	Introduction	173
7.2	Identification of nature, goal, team, environment, modality, knowledge transformation, cognitive action, reasoning, and visual transformation as the main parameters for conceptual architectural collaboration design.	174

7.3	The sketch modality supports high frequencies of cognitive actions, knowledge transformation, reasoning and visual transformation during conceptual architectural collaboration design.	175
7.4	Knowledge transformation through cognitive actions, reasoning and visual transformation during conceptual architectural collaboration design	176
7.5	<i>Socialization</i> and <i>combination</i> positively relate to aesthetic, proficiency, creativity and technicality in sketch based conceptual architectural collaboration design.	176
7.6	Propose Integrated Thinking Pattern for conceptual architectural collaboration design.	177
7.7	Contribution	181
7.8	Limitation	181
7.9	Recommendations	182
7.10	Significance	182
7.11	Future Study	183

REFERENCES	185
-------------------	------------

APPENDICES	229
-------------------	------------

LIST OF TABLES

TABLE NO.	TITLE	PAGE
4.1:	Research Methods	107
4.2:	Current Research Design	108
4.3:	Research Set-up	109
4.4:	REVIT software Design Schedule	115
4.5:	Sketch Design Schedule	115
4.6:	The Research Observation	120
4.7:	The variables for the scores (Dorst and Cross, 2001)	122
4.8:	Data Transcribing (Digital)	127
4.9:	Coding Matrix	130
4.10:	Coding Designers act of Knowledge Transformation	133
4.11:	Coding Designers act of Cognitive action	135
4.12:	Coding Designers act of Reasoning	137
4.13:	Coding Designers act of Transformation	138
4.14:	Frequency Tabulation of Sketch	140
4.15:	Frequency (f) Tabulation of Digital	140
4.16:	Duration (mins) Tabulation of Sketch	141
4.17:	Duration (mins) Tabulation of Digital	141
4.18:	Evaluators' Score (Sketch)	144
4.19:	Evaluators' Score (Digital)	145
5.1:	Collaborative constructs type, variables and codes	150
5.2:	Example of Knowledge Transformation and Cognitive Actions taken from one of the sketch session	152
5.3:	Example of Reasoning Strategy taken from one of the sketch session	156

6.1:	The Chi-square Result Output	160
6.2:	Frequency of Cognitive action	161
6.3:	Correlation of Knowledge Transformation and Parameters of Conceptual architectural collaboration design (Sketch)	162
6.4:	Correlation of Knowledge Transformation and Parameters of Conceptual architectural collaboration design (Digital)	163
6.5:	Relationship of Productivity of knowledge transformation in collaboration design.	165
6.6:	Describing the pattern of Action in Conceptual Architectural Collaboration Design	167
6.7:	Abductive and Deductive Reasoning in Conceptual Architectural Collaboration Design	168
6.8:	Deductive and Inductive Reasoning in Conceptual Architectural Collaboration Design	169
6.9:	Describing <i>knowledge Transformation</i> in Conceptual Architectural Collaboration Design	170
7.1:	Team 1, Verbal conversation in design collaboration (Digital)	234
7.2:	Team 1, Verbal conversation in design collaboration (Sketch)	235
7.3:	Team 1, Coding process (Digital)	235
7.4:	Team 1, Coding process (Sketch)	236
7.5:	Team 1, Coding summary (Digital)	237
7.6:	Team 1, Coding summary (Sketch)	238
7.7:	Team 2, Verbal conversation in design collaboration (Digital)	240
7.8:	Team 2, Verbal conversation in design collaboration (Sketch)	240
7.9:	Team 2 Coding process (Digital)	241
7.10:	Team 2 Coding process (Sketch)	242
7.11:	Team 2 Coding summary (Digital)	243
7.12:	Team 2 Coding summary (Sketch)	244
7.13:	Team 3, Verbal conversation in design collaboration (Digital)	246
7.14:	Team 3, Verbal conversation in design collaboration (Sketch)	248
7.15:	Team 3 Coding process (Digital)	250
7.16:	Team 3 Coding process (Sketch)	253
7.17:	Team 3 Coding summary (Digital)	255
7.18:	Team 3 Coding summary (Sketch)	256

7.19:	Team 4, Verbal conversation in design collaboration (Digital)	258
7.20:	Team 4, Verbal conversation in design collaboration (Sketch)	262
7.21:	Team 4 Coding process (Digital)	269
7.22:	Team 4 Coding process (Sketch)	270
7.23:	Team 4 Coding summary (Digital)	272
7.24:	Team 4 Coding summary (Sketch)	272
7.25:	Team 5 Verbal conversation in design collaboration (Digital)	276
7.26:	Team 5 Verbal conversation in design collaboration (Sketch)	277
7.27:	Team 5 Coding process (Digital)	278
7.28:	Team 5 Coding process (Sketch)	279
7.29:	Team 5 Coding summary (Digital)	281
7.30:	Team 5 Coding summary (Sketch)	282
7.31:	Team 6 Verbal conversation in design collaboration (Digital)	284
7.32:	Team 6 Verbal conversation in design collaboration (Sketch)	285
7.33:	Team 6 Coding process (Digital)	286
7.34:	Team 6 Coding process (Sketch)	287
7.35:	Team 6 Coding summary (Digital)	288
7.36:	Team 6 Coding summary (Sketch)	289
7.37:	Team 7 Verbal conversation in design collaboration (Digital)	292
7.38:	Team 7 Verbal conversation in design collaboration (Sketch)	293
7.39:	Team 7 Coding process (Digital)	294
7.40:	Team 7 Coding process (Sketch)	295
7.41:	Team 7 Coding summary (Digital)	297
7.42:	Team 7 Coding summary (Sketch)	297
7.43:	Team 8 Verbal conversation in design collaboration (Digital)	300
7.44:	Team 8 Verbal conversation in design collaboration (Sketch)	301
7.45:	Team 8 Coding process (Digital)	302
7.46:	Team 8 Coding process (Sketch)	305
7.47:	Team 8 Coding summary (Digital)	306
7.48:	Team 8 Coding summary (Sketch)	307

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1:	Research Framework (Ackoff, 1989 in Rowley, 2007, p.163)	9
1.2:	Structure of Thesis	13
2.1:	Knowledge taxonomy (adopted from Vasconcelos et al., 2000, p.7)	29
2.2:	BIM-based assumption of conceptual architectural collaboration design	33
3.1:	A theoretical framework for conceptual architectural collaboration design	55
3.2:	The two types of shared environment (Rahman et al., 2013, p.412)	61
3.3:	Synchronous environment (Rahman et al., 2013, p.412)	63
3.4:	Asynchronous environment (Rahman et al., 2013, p.412)	64
3.5:	The Sketch Modality	75
3.6:	Digital design modality	78
3.7:	Process of knowledge transformation (Nonaka et al., 2000, p.12)	83
3.8:	Knowledge Background (Nonaka et al., 2000, p.20)	85
3.9:	Knowledge Space (Nonaka et al., 2000, p.16)	87
3.10:	Example of cognitive action pattern (Valkenburg and Dorst, 1998, p.254)	92
3.11:	Example of a Reasoning Pattern (Dorst, 2011, p.523-524)	96
4.1:	Research Framework	104
5.1:	Example of Knowledge Transformation and Cognitive Actions taken from one of the sketch session	153

5.2:	Example of Reasoning Strategy taken from one of the sketch session	157
6.1:	Frequency and Duration Difference between Sketch and Digital Modalities	161
6.2:	Modality Based Relationship between Cognitive Actions and Knowledge Transformation in Architectural Collaboration design	164
6.3:	Relationship of Productivity of knowledge transformation in collaboration design.	165
6.4:	Cognitive Action Pattern in Conceptual Architectural Collaboration Design	166
6.5:	Reasoning Pattern in Conceptual Architectural Collaboration Design	168
6.6:	Knowledge Transformation Pattern in Conceptual Architectural Collaboration Design	169
7.1:	Integrated thinking pattern for Architectural Collaboration design	178
10.1:	Research environment	229
10.2:	Mock-up station	229
10.3:	Sketch station	230
10.4:	Digital station	230
10.5:	Design Brief (Digital)	231
10.6:	Design Brief (Sketch)	232
10.7:	Team 1 Sketch / Digital Sessions	233
10.8:	Team 1 Sketch sheets	233
10.9:	Team 1 Digital sheets	234
10.10:	Team 2 Digital session	239
10.11:	Team 2 Sketch sheets	239
10.12:	Team 2 Digital sheets	240
10.13:	Team 3 Sketch sessions	245
10.14:	Team 3 Sketch sheets	245
10.15:	Team 3 Digital sheets	246
10.16:	Team 4 Sketch sessions	257
10.17:	Team 4 Sketch sheets	257
10.18:	Team 4 Digital sheets	258
10.19:	Team 5 Mock-up session	275

10.20:	Team 5 Sketch sheets	275
10.21:	Team 5 Digital sheets	276
10.22:	Team 5 Digital sessions	283
10.23:	Team 6 Sketch sheets	283
10.24:	Team 6 Digital sheets	284
10.25:	Team 7 Digital sessions	291
10.26:	Team 7 Sketch sheets	291
10.27:	Team 7 Digital sheets	292
10.28:	Team 8 Digital sessions	299
10.29:	Team 8 Sketch sheet	299
10.30:	Team 8 Digital sheets	300
10.31:	Team 1 coding validation sheet (Digital)	309
10.32:	Team 1 coding validation sheet (Sketch)	309
10.33:	Team 2 coding validation sheet (Digital)	310
10.34:	Team 2 coding validation sheet Sketch)	310
10.35:	Team 3 coding validation sheet (Digital)	311
10.36:	Team 3 coding validation sheet (Sketch)	311
10.37:	Team 4 coding validation sheet (Digital)	312
10.38:	Team 4 coding validation sheet (Sketch)	312
10.39:	Team 5 coding validation sheet (Digital)	313
10.40:	Team 5 coding validation sheet (Sketch)	313
10.41:	Team 6 coding validation sheet (Digital)	314
10.42:	Team 6 coding validation sheet (Sketch)	314
10.43:	Team 7 coding validation sheet (Digital)	315
10.44:	Team 7 coding validation sheet (Sketch)	315
10.45:	Evaluator 1 score sheet (Sketch)	317
10.46:	Evaluator 1 score sheet (Digital)	317
10.47:	Evaluator 2 score sheet (Sketch)	318
10.48:	Evaluator 2 score sheet (Digital)	318
10.49:	Evaluator 3 score sheet (Sketch)	319
10.50:	Evaluator 3 score sheet (Digital)	319
10.51:	Evaluator 4 score sheet (Sketch)	320
10.52:	Evaluator 4 score sheet (Digital)	320
10.53:	Evaluator 5 score sheet (Sketch)	321

10.54:	Evaluator 5 score sheet (Digital)	321
10.55:	Evaluator 6 score sheet (Sketch)	322
10.56:	Evaluator 6 score sheet (Digital)	322
10.57:	Evaluator 7 score sheet (Sketch)	323
10.58:	Evaluator 7 score sheet (Digital)	323
10.59:	Evaluator 8 score sheet (Sketch)	324
10.60:	Evaluator 8 score sheet (Digital)	324

LIST OF SYMBOLS

2D	-	Two dimensional
3D	-	Three dimensional
ABD	-	Abduction
A-D-I	-	Abduction-deduction-induction
AI	-	Artificial intelligence
AIA	-	American institute of architects
BIM	-	Building information modeling
CA	-	Cognitive action
CAAD	-	Computer aided architectural design
CAD	-	Computer aided design
CHD	-	Center for Health Design
CITIS	-	Collaborative virtual organization
COM	-	Combination
CSCW	-	Computer supported collaborative works
D-E	-	Deduction-abduction
DED	-	Deduction
D-I	-	Deduction-induction
DIKW	-	Data, information, knowledge, wisdom
DSM	-	Distance shared media
DT	-	Design transformation
EBD	-	Evidence based design

EE	-	Explicit-explicit
ET	-	Explicit-tacit
EXT	-	Externalization
<i>f</i>	-	Frequencies
F2F	-	Face 2 face
FBS	-	Functional behavior structure
F-M	-	Framing-moving
F-R	-	Framing-reflecting
FRM	-	Framing
FTF	-	Face to face
HD	-	High definition
HVAC	-	High voltage air conditioning
ICT	-	Information communication technology
IDT	-	Immersive Discussion Tool
IFC	-	Industry Foundation Classes
IND	-	Induction
INT	-	Internalization
IPD	-	Integrated project delivery
I-S-E-C		Internalization-socialization-externalization-combination
KT	-	Knowledge transformation
LOD	-	Level of development
LSA	-	Latent semantic analysis
LTR	-	Lateral
MAVDCS	-	Multi-agent virtual design shared media system
MEP	-	Mechanical, electrical and plumbing
<i>min</i>	-	Minutes
MOV	-	Moving

NAM	-	Naming
NF	-	Naming-framing
N-F-M-R	-	Naming-framing-moving-reflecting
N-F-R-M	-	Framing-reflecting-moving
NVIVO	-	Analysis software
REF	-	Reflecting
RIBA	-	Royal institute of British architects
RS	-	Reasoning strategies
SECI	-	Socialization, externalization, combination and internalization
S-E-C-I	-	Socialization-externalization-combination-internalization
SOC	-	Socialization
SPSS	-	Statistics software
TE	-	Tacit-explicit
TT	-	Tacit-tacit
TUE	-	Technische Universiteit Eindhoven
TUI	-	Tangible user interface
UTM	-	Universiti teknologi Malaysia
VER	-	Vertical
VR	-	Virtual reality
VR3D	-	Virtual reality and three dimensional
VRML	-	Virtual reality modeling language

CHAPTER 1

INTRODUCTION

1.1 Introduction

The design may be described as a set of activities which are required in the development of a new product or service or system (Mosley et al., 2018). This involves a process of the mind which has been described by Schon (1983) as either reflection-in-action or reflection-on-action. Underpinning this description are complex concepts such as Linkography (Goldschmidt, 1995), function-behavior-structure (Gero, 1990), and frame-move-evaluation (Schon, 1983). In addition, Lawson (2004) has identified three major design processes which need to be considered and these are analysis, synthesis, and evaluation whereas, from a different point of view RIBA, (2013) point out that the key issues are conceptualization, development and technology.

According to Froese (2010) due to conditions associated with time, quality, cost and performance, the act of design is preferably better under a digital modality supported collaborative practice. Similarly, literature statistics have shown that adopting digital modality supported collaborative practice will vigorously remedy the profligacy of information, communication, resources and time facing the conventional design process (Garber, 2014; Bråthen, 2015; Luyten 2015).

However, due to the reflective nature of design, facilitating cognitive functions like actions, thinking, reasoning, sketching and visual transformation in a digital modality supported collaborative setting might imbue highly differentiated strategy, approach and modality. Therefore, the need to support cognitive design functions in a digital modality supported collaborative conceptual architectural design practice will be the focus area for this research.

1.2 Background to the Study

Two most distinctive characteristics of digital modality supported collaborative practice are focusing on a defined common goal that represents a collective input and output of all stakeholders and the challenge of managing team integration and dynamism (Stahl, 2006; Boud et al., 1999; Preece and Rombach, 1994; Huxham, 1996; Hord, 1986). Thus, the background study of digital modality supported collaborative practice in design should include a literature framework that explicitly define how can two or more designers achieve a defined common design goal that represents their collective input and output. Therefore, in the following paragraphs this research review relevant background literature on collaboration in the context design.

Sonnenwald (1996) explore on the role of collaboration in design. The study established that knowledge about communication support provides insight on the functionality of methods and tools of multidisciplinary design collaboration. In 1995, design studies journal organized a workshop on design teamwork involving a team of one designer (Dan) and a team of three designers (Ivan, John, and Kerry) where each team worked over a period of two hours. Using this same workshop data, Goldschmidt (1995) investigates the cognitive differences between the lone designer and the three-member design team in order to understand who does better in design. The study found that there is no significant difference between the individual and the team in the way they bring their work to fruition. Therefore, the study concludes that team size almost has no significant advantage over an individual when it comes to fulfillment of design.

Similarly, using the same workshop data, Cross and Cross (1995) employed protocol studies to investigate on the demonstration of the applicability of cognitive processes in design team practice. The study portrayed an understanding of the role and relationships of the design team based on planning, action, information sharing and gathering, analyzing and understanding of design problems. The study found that based on the social process, in design there is a significant interaction between the technical and cognitive process among designers in design teamwork.

Valkenburg and Dorst (1998) empirically identified and measured the structure of reflective practice of the design team. The study develops a pattern of reflective practice for a design team that indicates a differential pattern of behavior between teams based on naming, framing, moving and reflecting. The study has the only study that investigates the actual nature of design as shown in design theories in design teamwork. Chiu (2002) examined the organizational view of design communication in design collaboration. The study established that team organization in architectural design collaboration is better structured in practice than studios because design goal is more specific and often well defined in the architectural practice. Whereas, the study of Dong (2005) explored on communication and artifact knowledge construction of design team. The study established that similarities of language bridges indirect relations among designers mind which leads to a constructed shared mental representation of design artifacts. The study provides an initial background for understanding knowledge construction in design collaboration.

Stempfle and Badke-schaub (2002) investigate the thinking approach of the design team. The study distinguished between operations that serve to widen a problem space (generation, exploration) from operations that serve to narrow a problem space (comparison, selection) in design collaboration. Gabriel and Maher (2002) coded and modeled communication in architectural collaborative design to develop a coding scheme for the investigation of difference between computer-mediated collaborative design and face to face collaborative designs, to establish computer-mediated and communication tools for collaborative design. The study concludes that the nature of collaboration either computer-mediated collaborative design or face to face

collaborative designs it does not make any significant difference in communication during the interaction.

Gül and Maher (2007) analyzed the impact of different settings on team design by comparing face-to-face sketching to designing in virtual environments collaborative design environments. The study concludes that changes in the design behavior can be categorized in two different ways: the effect of being in the same location and the effect of the type of external representations. Rahimian and Ibrahim (2011) discovered the differences between 3D and manual sketching techniques using protocol analysis of three peers of novice architectural designers. The study found that haptic-based design interface improved designers' cognitive and collaborative activities.

Testing of co-located and remote activities in virtual and face to face environment by Gu et al. (2011) indicated the potentials of three-dimensional virtual worlds against traditional co-located manual sketching and remote sketching using the smart board for supporting remote collaboration in design and tangible user interfaces (TUI) for enhancing co-located collaboration in design. Finally, the findings of the protocol analysis of four peers of professional architects for 3D world and three peers of second and third year architecture design students for TUI indicated that the three dimensional virtual worlds sufficiently support collaboration in design, whereas TUI session tend to establish more cognitive synchronization through active negotiation processes of three dimensional blocks where designers produced more perceptual activities. Ibrahim and Rahimian (2010) found that current conventional CAD tools are advantageous for detailed engineering design but, they hinder novice designers' creativity.

Mathew (2013) analyzed the potential of collaboration supporting technologies in a studio learning environment. The study provides evidence that supports the creation of a single digital building model by a student and group in a studio-based learning environment. Rahman et al. (2013) compared the effect of synchronous and asynchronous settings on team design process. The findings of the study provided clear

indications that phase-specific usage of the shared object in the synchronous setting is better than the asynchronous settings. Feast (2012) determined the significance of teamwork in professional collaborative design work. The study concludes that the development of support for collaborative design should target not only problem-solving but also informal social interactions. Jutraz and Zupancic (2014) determine the importance of interdisciplinary collaborative design studios about whether architects learn anything new through interdisciplinary collaboration, and how such collaboration could be improved. The study found that it is important to incorporate interdisciplinary course for architecture students.

Based on extensive background study so far, it can be seen that most of the literature are found to have used protocol analysis method to investigate the role of technology, teamwork, communication and environment in a collaboration design setting. Whereas, issues like how to facilitate cognitive design functions like actions, thinking, reasoning, sketching and visual transformation in a digital modality supported collaborative settings fall short of proper investigation and explanation. Therefore, this thesis will focus on the subsequent problem emerging from the background study to pursue the context of the study.

1.3 Problem Statement

Digital modality supported collaborative practice is a means that encourage growth-oriented development associated with improving the efficiency of the architectural design process. Its application has been calculated by many literature statistics to have a significant impact on the quality, efficiency, and productivity of the design process (Azmi et al., 2018; Succar, 2009; Garber, 2014; Succar, 2009; Bryde et al., 2013; Lee, 2008). However, the issue of how the new approach can support the flexible nature of cognitive design functions like actions, thinking, reasoning, sketching and visual transformation is one of the emerging problem hindering its acceptance into a dominant silo conventional practice (Migilinskas et al., 2013).

Although, Jonson (2005) suggested that the future may offer a friendlier digital modality supported collaboration practice. Yet to date Jonson's suggestion have not been empirically supported.

Thus, the application of digital modality supported collaborative practice in design is a bit problematic, notably in the way, it can support cognitive design functions like actions, thinking, reasoning, sketching and visual transformation during conceptual architectural collaboration design. Therefore, this research problem statements reads as;

“Digital modality supported collaborative practice need to support flexible cognitive functions during conceptual architectural collaboration design.”

1.4 Research Gap

Conceptual architectural design stage is a complex activity that involve highly human cognitive design functions like actions, thinking, reasoning, sketching and visual transformation (Valkenburg and Dorst, 1998; Dorst, 2011; Goel, 1994; Goldschmidt and Weil, 1998; Schon, 1983). In contrast, contemporary conditions promotes digital modality supported collaborative practice for the design, without explicitly establishing how multitude designers perform key human cognitive design functions like group actions, thinking, reasoning, sketching and visual transformation in a digital modality supported collaborative design environment (Vaishnavi and Kuechler, 2015; Preece et al., 2015; Hardin and McCool 2015; Kasali and Nersessian, 2015). To this end, this study proposes to investigate cognitive design functions during digital modality supported conceptual architectural collaboration design practice. These prompt to define the study research gap as:

“even though digital modality supported collaborative practice presumes improving the design, yet there is no clear theoretical or practical proving of how multitude designers perform key cognitive design activities like group actions, thinking, reasoning, sketching and visual transformation during conceptual architectural collaboration design (research gap).”

1.5 Research Aim

The aims to investigate conceptual architectural collaboration design and the implications of sketch and digital modalities.

1.6 Research Objectives

1. To propose the theoretical framework for collaboration in design.
2. To determine the impact of modalities on conceptual architectural collaboration design.
3. To establish the parameters of tacit knowledge transformation in conceptual architectural collaboration design.
4. To ascertain the relationship between knowledge transformation and productivity during conceptual architectural collaboration design.
5. To develop the pattern for conceptual architectural collaboration design.

1.7 Research Questions

1. What is the theoretical framework for collaboration in design?

2. What is the impact of modality on conceptual architectural collaboration design?
3. What are the parameters of tacit knowledge during conceptual architectural collaboration design?
4. Can knowledge transformation ascertain the productivity of collaboration during conceptual architectural collaboration design?
5. Is there pattern for conceptual architectural collaboration design?

1.8 Research Significance

Integrating the concept of digital modality supported collaboration in conceptual architectural design necessitates the invention of new theory as a contribution to the body of design knowledge in both architectural education and practice. This thesis will provide the parameters and pattern of the much anticipated conceptual architectural collaboration design.

1.9 Research Framework

The Data, Information, Knowledge, and Wisdom model (DIKW model) of hierarchical knowledge process (Ackoff, 1989) was adopted to frame the knowledge development process of this research investigation. According to Ackoff, the data is raw material that simply exists in any form or format and has no significance beyond its existence usability or not. The information is when the data has been given meaning by way of relational analysis or connection. This “meaning” can be useful, based on the rationale behind what data has been used. The knowledge is the appropriate understanding of the information, such that it becomes useful. Finally wisdom is a strictly human process that deals with moral and ethical codes that provide the understanding about which there has previously been no understanding, and in doing

so, goes far beyond knowledge to become rather a human cognitive, philosophical probing (Ackoff, 1989).

Ackoff indicates that the first three categories relate to the past; they deal with what has been or what is known. Only the fourth category, wisdom, deals with the future because it incorporates vision. With wisdom, people can create the future rather than just grasp the present and past. However, achieving wisdom is not easy; people must move successively through the other categories. It can be noticed that the DIKW model prescribes a linear sequential hierarchy of knowledge processes. In reality, knowledge hierarchy can be iterative depending on the case under consideration. Nevertheless, the DIKW model is still used in many forms and shapes to look at the extraction of value and meaning of knowledge hierarchy. As shown in Figure 1.1 this study adopts the perspective of the DIKW knowledge hierarchy to frame the research.

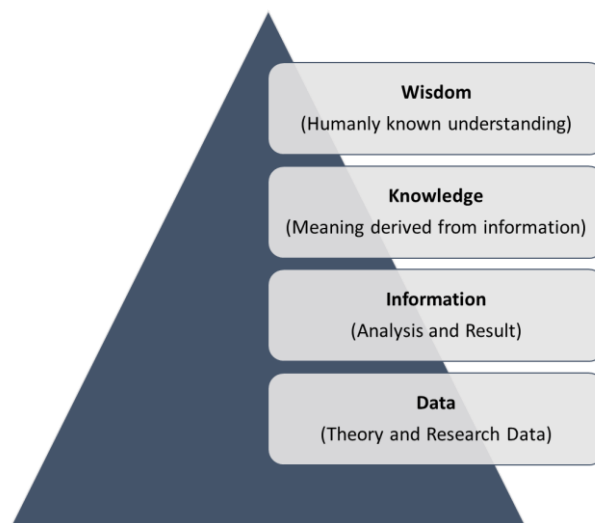


Figure 1.1: Research Framework (Ackoff, 1989 in Rowley, 2007, p.163)

In the context of this research, the data is framed as the literature review and records collected from our research measurements. The information is framed as the outcome results of the analysis of the research data. It is the transformation of the research data into a particular category of information that represents the initial requirement for the data gathering. Likewise, the next stage is knowledge which is

framed as the useful meaning derived from the information which is significantly connected with the initial research problem, aim, objectives and questions.

However, at this stage, the knowledge cannot infer further understanding because it does not contain true cognitive and analytical ability that is only encompassed by a human which is contained in the next level of wisdom. The stage of wisdom is a frame that the understanding of the research topic or area has reached a stage whereby if questions are asked to which there is no humanly-known answer, wisdom can supply the answer. Therefore, it is the process by which I also discern, or judge, between right and wrong and good about conceptual architectural collaboration design. It is the unique state of understanding of the soul of conceptual architectural collaboration design. Thus, the structure of the DIKW is suitable to describe the research frame adopted for this thesis.

1.10 Research Methodology

In carrying out the research investigation, this study employs an empirically and contextually methodological choice known as mixed research method (Creswell, 2012). The method will use cross-sectional design experiment involving design teams solving a given design issue (Creswell, 2012). The cross-sectional experiment will offer the opportunity to investigate on what it takes to design while collaborating. Thus, from the perspective of the mixed research method the research philosophy, approach, time horizon and tactics are selected to satisfy the research aim and objectives. This research begins with establishing the fundamental framework of the integration of design and collaboration.

Similarly, the research approach is analysing, because the analysing research approach is not the conventional direct move from literature to data (as in deduction) or data to literature (as in induction), but rather a zigzag move between data-literature-data to establish that which is not yet known. It represents a value wanting to be

achieved, as in this case designing while collaborating (Saunders et al., 2015). Interpretive research philosophy that entails a phenomenon is also suitable for the research. The interpretivism here implies the use of observation (Merriam and Tisdell, 2016).

1.11 Research Scope

This research is driven from the theoretical perspective of the significant role of digital modality on. The research proceeds by identifying parameters for successful conceptual architectural collaboration design, before scoping to the research dependent, independent and controlled variables within the identified parameters. The study scope to a peer of unidisciplinary architectural design teams to control the effect clustering of more than two multidisciplinary stakeholders in a single environment to talk about the same issue (known as team dynamics). Secondly, this research adopts LOD300 (level of development) of the digital modality scale to maintain the originality of the conceptual phase of the design and the capability of the modalities.

1.12 Research Overview

Through contextual and empirical investigation this research will attempt to define conceptual architectural collaboration design. Zooming from the perspective of Kan and Gero (2010) this research will use protocol analysis to carry out the study. One of the major motivating factors for the research is the postulation of Ho et al. (2013) that collaboration in design would serve as a better option that can promote better practice with rich problem-solving clues. Some other benefits also include supporting the transformation of conventional design practice into a more advanced technology guided practice. It can be noticed that research investigation on the concept

of collaboration in design focusing on technology and environment has been taking place since the nineties.

However, such investigations focus mainly on collaborative technologies and environment (Wang et al., 2013; Xue et al., 2012; Gu et al., 2010). This can be due to the lack of relevant knowledge of how collaborative tools and environment to support design activities. Similarly, also there is the limited understanding of the actual impact such collaborative modalities can have on design. Thus, this research will investigate on what it means to collaborate while designing to advocate a differentiated understanding on how modalities can lead the way in providing the support for the actualization of effective conceptual architectural collaboration design.

1.13 Structure of Thesis

The structure of this thesis illustrated in Figure 1.2 explains the basic process from the start to the conclusion of the study. The major explanation is the understanding of what and how is a good integration of design and collaboration. What are the parameters required in achieving the stated objectives? Chapter 1 is the introductory chapter of the study which presents a summary of the research which is the overview and general foundation of the entire issue. The background further leads to the problem statements, research aim, question, and objectives.

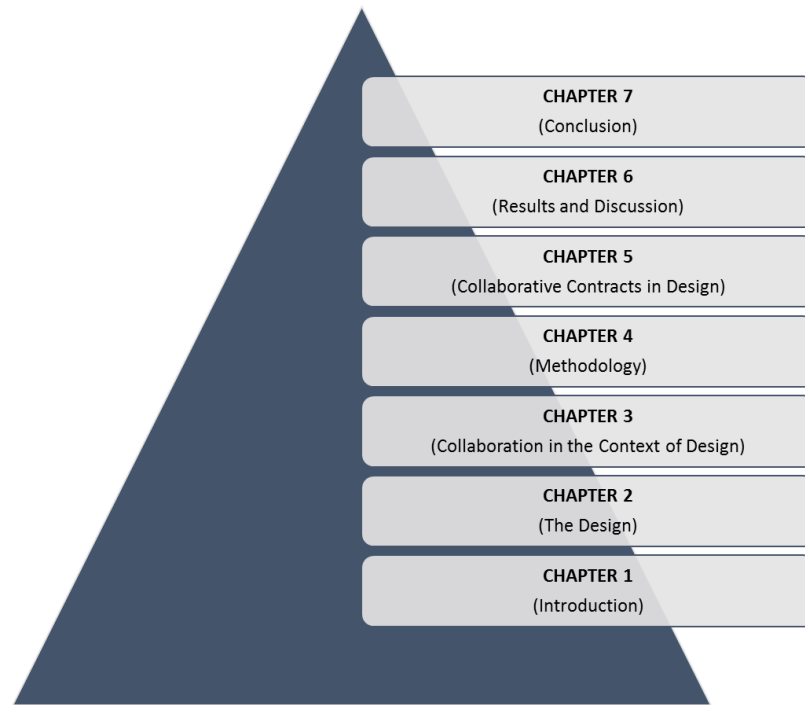


Figure 1.2: Structure of Thesis

Chapter 2 and 3 provides a theoretical background understanding of the integration of design and collaboration through an extensive review of current literature on both areas, some of which includes modalities. Furthermore, the chapter provides a theoretical understanding of the existing concept of conceptual architectural collaboration design through an extensive review of current literature research across the conventional and contemporary design process, some of which includes modalities.

Chapter 4 presents an overview of the methodology used to carry out the study. Here the actual structuring of the research method is carried out with a focus on the design process and collaboration, and critically discussing issues on research design, method, participants, sampling, and data. Finally, the chapter concludes with certain required factors for the data collection and also, describes the method used for the data collection, coding, and classification. The last part of the chapter explains the content of the data and explanation. The chapter indicates the core issues about the selection of the methodology and their relationship with the data.

Chapter 5 focuses on analysing the basic understanding and parameters of conceptual architectural collaboration design using protocol studies. The analysis was carried out with NVIVO, SPSS and Microsoft EXCEL software for data segmentation, coding, classification analysis and interpretation.

Chapter 6 deals with the results and discussion. The results and discussions are the useful information derived from the analysis. The chapter also presents the discussion of the result. The results derived from the analysis are used to generate some discussion which explains how the research question and objective are answered by the result. Therefore, this chapter provides answers to the research question in a discussion format.

Chapter 7 concludes the thesis by presenting answers and implications for further research. Finally, the thesis includes ten appendixes containing a sample of subjects, transcribed data, pictures coding, tabulation and publications.

REFERENCES

- Abdelmohsen, S. M., and Do, E. Y. L. (2007). TangiCAD: Tangible Interface for Manipulating Architectural 3D Models. In the 10th International Conference on Computer Aided Architectural Design Research in Asia (CAADRIA).
- Abrishami, S., Goulding, J., Rahimian, F. P., Ganah, A. and Sawhney, A. (2014). G-BIM framework and development process for integrated AEC design automation. *Procedia Engineering*, 85, 10-17.
- Achten, H. H. (2002). Requirements for collaborative design in architecture.
- Ackoff, R. L. (1989). From data to wisdom. *Journal of applied systems analysis*, 16(1), 3-9.
- Adams, R. and Atman, C. (1999) Cognitive Processes in Iterative Design Behavior. 29th ASEE/IEEE Frontiers in Education Conference. San Juan Puerto Rico.
- Adi, F. M., Khaidzir, K. A. M., and Said, I. (2015). Role of Conceptualisation as a Catalyst in Capturing Urban Issues within the Studio Learning Environment. *Procedia-Social and Behavioral Sciences*, 170, 165-176
- Aguero, C., Canas, J., Martin, F. and Perdices, E. (2010) Behavior-based Iterative Component Architecture for soccer applications with the Nao humanoid. IN *ROBOTS*, P. O. T. T. W. O. H. S. (Ed.). Humanoids, Nashville (USA).
- Ahmed, D. T. and S. Shirmohammadi (2008). "A Dynamic Area of Interest Management and Collaboration Model for P2P MMOGs." 27-34.

- Aish, R., and Woodbury, R. (2005, August). Multi-level interaction in parametric design. In International symposium on smart graphics (pp. 151-162). Springer, Berlin, Heidelberg.
- Akin, O. and Lin, C. (1995) Design protocol data and novel design decisions. *Design Studies*, 16, 26.
- Alavi, M., and Leidner, D. E. (2001). Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS quarterly*, 107-136.
- Alfano S. D. O. (2014). Team dynamics in clinical informatics. *Physician leadership journal*, 1(1), 58.
- Alkaslassy, E. (2011) How often do students working in two-person teams report that work was shared equitably? *Assessment and Evaluation in Higher Education*, 36. 367-375.
- Allert, H., and Richter, C. (2009). Design as Open-Ended Inquiry. *Creativity and Innovation Competencies on the Web-How does the "new" emerge with the support of Web Technologies. E-Creativity and e-Innovation. Salzburg Research Forschungsgesellschaft, Salzburg*, 4-5.
- Allert, H., and Richter, C. (2009, September). Design as knowledge creation. In *International Conference on Engineering and Product Design Education. EPDE (Vol. 9)*.
- Anderl, R., and Mendgen, R. (1996). Modelling with constraints: theoretical foundation and application. *Computer-Aided Design*, 28(3), 155-168.
- Andersen, H., and Wagenknecht, S. (2013). Epistemic dependence in interdisciplinary groups. *Synthese*, 190(11), 1881-1898.
- Andjomshoa, A., Islami, S. G., and Mokhtabad-Amrei, S. M. (2011). Application of Constructivist Educational Theory in providing Tacit Knowledge and

Pedagogical Efficacy in Architectural Design Education: A Case Study of an Architecture school in Iran'. *Life Science Journal*, 8(1), 213-233.

Anumba, C., Ugwu, o., Newnham, A. and Thorpe, A. (2002). "Collaborative design of structures using intelligent agents." *Automation in Construction* 11(1): 89-103.

Appley, D. G., and Winder, A. E. (1977). An evolving definition of collaboration and some implications for the world of work. *The Journal of Applied Behavioral Science*, 13(3), 279-291.

Ariyana, Y., and Wuryandari, A. I. (2012, April). Virtual interaction at virtual environment applied for Augmented Reality. In *Cloud Computing and Social Networking (ICCCSN)*, 2012 International Conference on (pp. 1-7). IEEE.

Ash, J. (2010). Architectures of affect: anticipating and manipulating the event in processes of videogame design and testing. *Environment and Planning D: Society and Space*, 28(4), 653-671.

Asimow, M. (1962). *Introduction to design*. Prentice-Hall.

Austin, S., Steele, J., Macmillan, S., Kirby, P., and Spence, R. (2001). Mapping the conceptual design activity of interdisciplinary teams. *Design studies*, 22(3), 211-232.

Azmi, N. F., Chai, C. S., and Chin, L. W. (2018). Building Information Modeling (BIM) in Architecture, Engineering and Construction (AEC) Industry: A Case Study in Malaysia. In *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate* (pp. 401-412). Springer, Singapore.

Bafoutsou, G., Mentzas, G. (2002). Review and functional classification of collaborative systems. *International journal of information management*. 22(4), 281-305.

- Barlish, K., and Sullivan, K. (2012). How to measure the benefits of BIM—A case study approach. *Automation in construction*, 24, 149-159.
- Bayer, B. E. (1976). U.S. Patent No. 3,971,065. Washington, DC: U.S. Patent and Trademark Office.
- Bedrick, J. (2008). Organizing the Development of a Building Information Model, *AECbytes*.
- Bilda, Z., and Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, 24(1), 27e50.
- Bilda, Z., Gero, J. and Purcell, T. (2006) To sketch or not to sketch? That is the question. *Design Studies* 613, 27, 27.
- Borkowski, A., Branki, C., Ewa Grabska, E. and Palacz, W. (2001). "Towards collaborative creative design." *Automation in Construction* 10(5): 607-616.
- Boud, D., Cohen, R. and Sampson, J. (1999, December) Peer learning and assessment.
- Boud, D., Keogh, R., and Walker, D. (1985). Promoting reflection in learning: A model. *Reflection: Turning experience into learning*, 18-40.
- Braha, D. and Maimon, O. (1997) The Design Process: Properties, Paradigms, and Structure. *IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans*, 27 n2, 146-166.
- Bråthen, K. (2015). "Collaboration with BIM - Learning from the Front Runners in the Norwegian Industry." *Procedia Economics and Finance* 21: 439-445.
- Bredeweg, B., Linnebank, F., Bouwer, A., and Liem, J. (2009). Garp3—Workbench for qualitative modelling and simulation. *Ecological informatics*, 4(5-6), 263-281.

- Brockwell, W. (2010) Leonardo Da Vinci. in www.forgottenbook.com (ed.) *Forgotten Books*. www.forgottenbook.com.
- Bryde, D., Broquetas, M., and Volm, J. M. (2013). The project benefits of building information modelling (BIM). *International journal of project management*, 31(7), 971-980.
- Bucciarelli, L. L. (2003). Designing and learning: a disjunction in contexts. *Design Studies*, 24(3), 295-311.
- Busby, J. (1998) *The Neglect of Feedback in Engineering Design Organizations*. *Design Studies*, 19, 14.
- Çağdaş, G., Özkar, M., Gül, L. F., and Gürer, E. (Eds.). (2017). *Computer-Aided Architectural Design. Future Trajectories: 17th International Conference, CAAD Futures 2017, Istanbul, Turkey, July 12-14, 2017, Selected Papers (Vol. 724)*. Springer.
- Cassell, C., and Johnson, P. (2006). Action research: Explaining the diversity. *Human relations*, 59(6), 783-814.
- Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F., and Gao, W. (2013). The evolution, challenges, and future of knowledge representation in product design systems. *Computer-aided design*, 45(2), 204-228.
- Chang, Y. Y., Gong, Y., and Peng, M. W. (2012). Expatriate knowledge transfer, subsidiary absorptive capacity, and subsidiary performance. *Academy of Management Journal*, 55(4), 927-948.
- Chau, K. W., Anson, M., and Zhang, J. P. (2005). 4D dynamic construction management and visualization software: 1. Development. *Automation in construction*, 14(4), 512-524.

- Chen, H. M., and Hou, C. C. (2014). Asynchronous online collaboration in BIM generation using hybrid client-server and P2P network. *Automation in Construction*, 45, 72-85.
- Chen, P. H., Cui, L., Wan, C., Yang, Q., Ting, S. K., and Tiong, R. L. (2005). Implementation of IFC-based web server for collaborative building design between architects and structural engineers. *Automation in construction*, 14(1), 115-128.
- Cheng, N. Y. W. (2003). Approaches to design collaboration research. *Automation in Construction*, 12(6), 715-723.
- Cheng, N., and Kvan, T. (2000, August). Design collaboration strategies. In *Proceedings of the Fifth International Conference on Design and Decision Support Systems in Architecture*, Ampt van Nijkerk (pp. 62-73).
- Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., and Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive science*, 13(2), 145-182.
- Chi, M. T., Glaser, R., and Rees, E. (1981). Expertise in problem solving (No. TR-5). Pittsburgh Univ PA Learning Research and Development Center.
- Chi, Y. A. N. G., Huang, F., and Noblesse, F. (2013). Practical evaluation of the drag of a ship for design and optimization. *Journal of Hydrodynamics, Ser. B*, 25(5), 645-654.
- Chin, L., Chai, C., Chong, H., Yusof, A. M., and bt Azmi, N. (2018). The Potential Cost Implications and Benefits from Building Information Modeling (BIM) in Malaysian Construction Industry. In *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate* (pp. 1439-1454). Springer, Singapore.
- Chiu, M. L. (2002). An organizational view of design communication in design collaboration. *Design studies*, 23(2), 187-210.

- Choi, J. H. (2014). A Study on the Development of a BIM Design Tool for Hanok Windows and Doors. *Journal of the Korea Academia-Industrial cooperation Society*, 15(12), 7331-7339.
- Chung, J. K., Kumaraswamy, M. M., and Palaneeswaran, E. (2009). Improving megaproject briefing through enhanced collaboration with ICT. *Automation in construction*, 18(7), 966-974.
- Ciribini, A. L. C., Ventura, S. M., and Paneroni, M. (2016). Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project. *Automation in Construction*.
- Clancey, W. J. (1993). Situated action: A neuropsychological interpretation response to Vera and Simon. *Cognitive Science*, 17(1), 87-116.
- Cooper, J. (Ed.). (2006). *Stepping into palliative care 1: Relationships and responses (Vol. 1)*. Radcliffe Publishing.
- Craft, B., and Cairns, P. (February 13-15, 2006). Work interaction design: Designing for human work. Paper presented at the IFIP TC 13.6 WG conference: Designing for human work, Madeira.
- Craig, D. L., and Zimring, C. (2002). Support for collaborative design reasoning in shared virtual spaces. *Automation in construction*, 11(2), 249-259.
- Creswell, J. W. (2012). *Educational research. Planning, conducting, and evaluating quantitative and qualitative research*.
- Cross, N. (1991). Models of the Design: Integrating Across the Disciplines. *Design Studies*, 12, 215-220.
- Cross, N. (1999). Natural intelligence in design. *Design Studies*, 20(1), 25e39.
- Cross, N. (2000). Designery ways of knowing: design discipline versus design science. *design (plus)*.

- Cross, N. (2007). *Designerly ways of knowing*. (paperback edition). Basel, Switzerland: Birkhwauser.
- Cross, N. and Anita, C. (1996) *Winning by Design: the methods of Gordon Murray, racing car designer*. *Design Studies*, 17, 91-107.
- Cross, N., and Cross, A. C. (1995). *Observations of teamwork and social processes in design*. *Design studies*, 16(2), 143-170.
- Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Sage.
- Czmoch, I., and Pękala, A. (2014). *Traditional Design versus BIM Based Design*. *Procedia Engineering*, 91, 210-215.
- Danfulani, B. I., and Anwar, M. K. K. (2015). *Design-Based Learning a Dichotomy of Problem-Based Learning*. *Advanced Science Letters*, 21(7), 2419-2424.
- Dave, B., and Koskela, L. (2009). *Collaborative knowledge management—A construction case study*. *Automation in construction*, 18(7), 894-902.
- Davenport, T. H., and Prusak, L. (2005). *Knowledge management in consulting. The contemporary consultant*, 305-326.
- Day, E.A., Arthur, W., Bell, S.T., Edwards, B.D., Bennett, W., Mendoza, J.L., and Tubre, T.C. (2005). *Ability -based pairing strategies in the team-based training of a complex skill; Does the intelligence of your training partner matter?* *Intelligence*, 33, 39-65.
- De Houwer, J., Barnes-Holmes, D., and Moors, A. (2013). *What is learning? On the nature and merits of a functional definition of learning*. *Psychonomic bulletin and review*, 20(4), 631-642.

- Defila, R., Di Giulio, A. (1998): Interdisziplinarität und Disziplinarität. In: Olbertz, J.-H. (Eds.): Zwischen den Fächern - über den Dingen? Universalisierung versus Spezialisierung akademischer Bildung. Opladen: 111-137.
- Delavari, N., Ibrahim, R., Sheik Said, N., and Abdullah, M. T. (2013). IT-integrated design collaboration engagement model for interface innovations. *WSEAS Transactions on Information Science and Applications*, 10(9), 285-302.
- Dennis, A. R., and Kinney, S. T. (1998). Testing media richness theory in the new media: The effects of cues, feedback, and task equivocality. *Information systems research*, 9(3), 256-274.
- Dennis, A. R., Fuller, R. M., and Valacich, J. S. (2008). Media, tasks, and communication processes: A theory of media synchronicity. *MIS quarterly*, 32(3), 575-600.
- Dennis, A., and Valacich, J. (1999, January). Doing experimental research on collaboration technology. In Tutorial presented at the Hawaii International Conference on System Sciences, Maui, HI.
- Derlega, V. J., and Chaikin, A. L. (1977). Privacy and self-disclosure in social relationships. *Journal of Social Issues*, 33(3), 102-115.
- Devon, R., Hager, W., Sathianathan, D., Seaintive, D., and Nowé, M. (1998). Alliance by design: International student design teams. *age*, 3, 1.
- Dillenbourg, P., Traum, D., and Schneider, D. (1996, September). Grounding in multi-modal task-oriented collaboration. In *Proceedings of the European Conference on AI in Education*, 30 September, 1998 (pp. 401-407).
- Dillenbourg, Pierre. (1999). "What do you mean by collaborative learning?": 1-19.
- Ding, L. Y., Zhong, B. T., Wu, S., and Luo, H. B. (2016). Construction risk knowledge management in BIM using ontology and semantic web technology. *Safety science*, 87, 202-213.

- Do, E. Y. L., and Gross, M. D. (1996). Drawing as a means to design reasoning. In *AI and Design*.
- Dong, A. (2005). The latent semantic approach to studying design team communication. *Design Studies*, 26(5), 445-461.
- Dong, K., and Doerfler, J. (2010). The Interdisciplinary Design Studio: Understanding Collaboration. In *Structures and Architecture: ICASA 2010-1st International Conference on Structures and Architecture*, July 21-23 July, 2010 in Guimaraes, Portugal (p. 261). CRC Press.
- Dorst, K. (1995). Analysing design activity: new directions in protocol analysis.
- Dorst, K. (1997). Describing design: a comparison of paradigms. Technische Universiteit Delft.
- Dorst, K. (2006). Design Problems and Design Paradoxes. *Design Issues*, 22(3), 4–17.
- Dorst, K. (2011). The core of ‘design thinking’ and its application. *Design studies*, 32(6), 521-532.
- Dorst, K. and Cross, N. (2001) Creativity in the design process: co-evolution of problem–solution. *Design Studies*, 22, 425–437.
- Dorst, K., and Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design studies*, 16(2), 261-274.
- Dorst, K., and Vermaas, P. E. (2005). John Gero’s Function-Behaviour-Structure model of designing: a critical analysis. *Research in Engineering Design*, 16(1-2), 17-26.
- Dorta, T., Lesage, A., Pérez, E., and Bastien, J. C. (2011). Signs of collaborative ideation and the hybrid ideation space. In *Design Creativity 2010* (pp. 199-206). Springer, London.

- Dreyfus, S. E., and Dreyfus, H. L. (1980). A five-stage model of the mental activities involved in directed skill acquisition (No. ORC-80-2). California Univ Berkeley Operations Research Center.
- Dubberly, H., and Evenson, S. (2008). On modeling The analysis-synthesis bridge model. *Interactions*, 15(2), 57-61.
- Dube, K., Mansour, E. and Wu, B. (2005). Supporting collaboration and information sharing in computer-based clinical guideline management. 18th IEEE Symposium on Computer-Based Medical Systems (CBMS'05), IEEE.
- Duckett, H. (2002). Smoke and mirrors? Evaluating the use of reflective practice as a management learning technique.
- Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, 36, 145-151.
- Easa, N. (2011). Knowledge creation process and Innovation in Egyptian Banking Sector. In *Organization Learning, Knowledge and Capabilities Conference*.
- Easterby-Smith, M., Lyles, M. A., and Tsang, E. W. (2008). Inter-organizational knowledge transfer: Current themes and future prospects. *Journal of management studies*, 45(4), 677-690.
- Eckert, C. M., Cross, N., and Johnson, J. H. (2000). Intelligent support for communication in design teams: garment shape specifications in the knitwear industry. *Design studies*, 21(1), 99-112.
- Eckert, C. M., Stacey, M. K., and Clarkson, P. J. (2000, January). Algorithms and inspirations: creative reuse of design experience. In *Greenwich 2000 International Symposium: Digital Creativity*, University of Greenwich, London (pp. 1-10).

- Eckert, C., Clarkson, P. J., and Zanker, W. (2004). Change and customisation in complex engineering domains. *Research in engineering design*, 15(1), 1-21.
- Eckert, Claudia M., Nigel Cross, and Jeffrey H. Johnson. "Intelligent support for communication in design teams: garment shape specifications in the knitwear industry." *Design studies* 21.1 (2000): 99-112.
- Eijck, M. Van, Jochems, W., and Go, S. M. (2013). A sampled literature review of design-based learning approaches : a search for key characteristics, 717–732.
- El Asmar, J. P., and Mady, C. (2013). A Constructivist Approach to Design Teaching at the Postgraduate Level: The Case of an Interdisciplinary Design Programme at FAAD, NDU, Lebanon. *Procedia-Social and Behavioral Sciences*, 93, 531-538.
- Eppinger, S., Nukala, M. and Whitney, D. (1997) Generalized Models of Design Iteration Using Signal Flow Graphs. *Research in Engineering Design*, V9, 11.
- Eppler, M. J., and Sukowski, O. (2000). Managing team knowledge: core processes, tools and enabling factors. *European Management Journal*, 18(3), 334-341.
- Ericsson, K. and Simon, H. (1993) *Protocol analysis: verbal reports as data* Cambridge, MIT Press.
- Eris, O., Martelaro, N., and Badke-Schaub, P. (2014). A comparative analysis of multimodal communication during design sketching in co-located and distributed environments. *Design Studies*, 35(6), 559-592.
- Feast, L. (2012). "Professional perspectives on collaborative design work." *CoDesign* 8(4): 215-230.
- Fernando, T. P., Wu, K. C., and Bassanino, M. N. (2013). Designing a novel virtual collaborative environment to support collaboration in design review meetings. *Journal of Information Technology in Construction*, 18, 372-396.

- Fiegen, A., Cherry, B. and Watson, K. (2002). "Reflections on collaboration: Learning outcomes and information literacy assessment in the business curriculum." *Reference Services Review* 30(4): 307-318.
- Finke, R. (1990) *Creative imagery: discoveries and inventions in visualization*, Hillsdale, NJ, Erlbaum.
- Fish, J. (2003) *Cognitive catalysis: sketches for a time-lagged brain* in G Goldschmidt and W L Porter (eds) *Design representation*, London, Springer Verlag.
- Fish, J. and Scrivener, S. (1990) *Amplifying the Mind's Eye: Sketching and Visual Cognition*. *Leonardo*, 23, 10.
- Ford, J. K., and Höllerer, T. (2008). *Augmented Reality: Information for Workplace Decision-Makers, Managers, Workers and Researchers*. *Handbook of Research on Virtual Workplaces and the New Nature of Business Practices*, Hershey, NY: Idea Group Publishing, 486-502.
- Fornos, R. A. (2015). "Digital models applied to the analysis, intervention and management of architectural heritage." 1: 407-418.
- Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., and Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, 41(10), 1081–1110.
- Friedman, K. (2000). *Creating design knowledge: from research into practice*.
- Froese, T. M. (2010). The impact of emerging information technology on project management for construction. *Automation in construction*, 19(5), 531-538
- Frost, P. and P. Warren (2000). Virtual reality used in a collaborative architectural design process. *Information Visualization*, 2000. Proceedings. IEEE International Conference on, IEEE.

- Fruchter, R. (1999). A/E/C teamwork: A collaborative design and learning space. *Journal of Computing in Civil Engineering*, 13(4), 261-269.
- Fruchter, R. (2003). Degrees of Engagement in Interactive Workspaces. *Proceedings 2nd Social Intelligence Design*
- Furlinger, K. and Moore, S. (2008) Detection and Analysis of Iterative Behavior in Parallel Applications. ICCS. Berlin, Springer-Verlag.
- Gabriel, G. C., and Maher, M. L. (2002). Coding and modelling communication in architectural collaborative design. *Automation in construction*, 11(2), 199-211.
- Gabriel, G., and Maher, M. L. (2000). An analysis of design communication with and without computer mediation. In *Collaborative design* (pp. 329-337). Springer, London.
- Garber, R. (2014). *BIM Design: Realising the Creative Potential of Building Information Modelling* (Vol. 2). John Wiley and Sons.
- Garner, S., and Mann, P. (2003). Interdisciplinarity: perceptions of the value of computer-supported collaborative work in design for the built environment. *Automation in construction*, 12(5), 495-499.
- Gero, J. S. (1990). Design prototypes: a knowledge representation schema for design. *AI magazine*, 11(4), 26.
- Gero, J. S., and Kannengiesser, U. (2008). An ontological account of Donald Schön's reflection in designing. *International Journal of Design Sciences and Technologies*, 15(2), 77-90.
- Gero, J. S., and McNeill, T. (1998). An approach to the analysis of design protocols. *Design studies*, 19(1), 21-61.
- Gero, J., Tversky, B. and Purcell, T. (2001) *Visual and Spatial Reasoning in Design II* Key Centre of Design Computing and Cognition, 12.

- Geyer, W., Richter, H., Fuchs, L., Frauenhofer, T., Daijavad, S., and Poltrock, S. (2001, September). A team collaboration space supporting capture and access of virtual meetings. In *Proceedings of the 2001 International ACM SIGGROUP Conference on Supporting Group Work* (pp. 188-196). ACM.
- Glock, F. (2009). Aspects of language use in design conversation. *CoDesign*, 5(1), 5–19.
- Goel, A., Zhang, G., Wiltgen, B. and Zhang, Y. (2015). "On the benefits of digital libraries of case studies of analogical design: Documentation, access, analysis, and learning." *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 29(02): 215-227.
- Goel, V. (1994). A comparison of design and nondesign problem spaces. *Artificial Intelligence in Engineering*, 9(1), 53-72.
- Goel, V. (1995) *Sketches of Thought*, Cambridge, Mass., MIT Press.
- Gold, A. H., and Arvind Malhotra, A. H. S. (2001). Knowledge management: An organizational capabilities perspective. *Journal of management information systems*, 18(1), 185-214.
- Goldschmidt, G. (1990). Linkography: assessing design productivity. In *Cybernetics and System'90, Proceedings of the Tenth European Meeting on Cybernetics and Systems Research* (pp. 291-298). World Scientific.
- Goldschmidt, G. (1991). The dialectics of sketching. *Creativity research journal*, 4(2), 123-143.
- Goldschmidt, G. (1995). The designer as a team of one. *Design Studies*, 16(2), 189-209.
- Goldschmidt, G. (2014). *Linkography: unfolding the design process*. Mit Press.

- Goldschmidt, G. and Smolkov, M. (1994) On visual design thinking: the visual kids of architecture *Design Studies* Vol 15, 16.
- Goldschmidt, G. and Smolkov, M. (2006) Variance in the impact of visual stimuli on design problem solving performance. *Design Studies* V27, 20.
- Goldschmidt, G., and Weil, M. (1998). Contents and structure in design reasoning. *Design issues*, 14(3), 85-100.
- Goodwin, G. P., and Johnson-Laird, P. N. (2005). Reasoning about relations. *Psychological review*, 112(2), 468.
- Gorse, C. A., and Emmitt, S. (2007). Communication behaviour during management and design team meetings: a comparison of group interaction. *Construction Management and Economics*, 25(11), 1197-1213.
- Gourlay, S. (2003). The SECI model of knowledge creation: some empirical shortcomings.
- Grant, D. (1979) *Design Methodology and Design Methods*. *Design Methods and Theories*, 13:1.
- Gray, B. (1989). *Collaborating: Finding common ground for multiparty problems*. NCJRS's biweekly e-newsletter, Jossey-Bass Publishers, San Francisco, CA 94103-1741. Pp 329. ISBN 1-55542-159-8
- Greeno, J. G., Collins, A. M., and Resnick, L. B. (1996). Cognition and learning. *Handbook of educational psychology*, 77, 15-46.
- Gregory, S. (1966) *The Design Method*, London, Butterworth Press.
- Grilo, A., and Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction*, 19(5), 522-530.

- Groat, L. N., and Wang, D. (2013). *Architectural research methods*. John Wiley and Sons.
- Gross, M. D., Do, E. Y. L., McCall, R. J., Citrin, W. V., Hamill, P., Warmack, A., and Kuczun, K. S. (1998). Collaboration and coordination in architectural design: approaches to computer mediated team work. *Automation in Construction*, 7(6), 465-473.
- Gu, N., Kim, M. J., and Maher, M. L. (2011). Technological advancements in synchronous collaboration: The effect of 3D virtual worlds and tangible user interfaces on architectural design. *Automation in Construction*, 20(3), 270-278.
- Gül, L. F., and Maher, M. L. (2007). Understanding design collaboration: Comparing face-to-face sketching to designing in virtual environments. *Proceedings IASDR 2007, The International Association of Societies of Design Research*.
- Gumienny, R., Gericke, L., Quasthoff, M., Willems, C., and Meinel, C. (2011, June). Tele-Board: Enabling efficient collaboration in digital design spaces. In *Computer Supported Cooperative Work in Design (CSCWD), 2011 15th International Conference on* (pp. 47-54). IEEE.
- Hack, G. and M. Canto (1984). "Collaboration and context in urban design." *Design Studies* 5(3): 178-184.
- Hamilton, D. K. (2003). The four levels of evidence-based practice. *Healthcare Design*, 3(4), 18-26.
- Han, Z., Lei, C., and Yang, J. (2006). Finding the Potential Opportunities for Collaboration Between Two Organizations by Noninteractive Literature based Knowledge Discovery. *Data Analysis and Knowledge Discovery*, 1(4), 45-48.
- Hardin, B., and McCool, D. (2015). *BIM and construction management: proven tools, methods, and workflows*. John Wiley and Sons.

- Hekkert, P., Mostert, M., and Stompff, G. (2003, June). Dancing with a machine: a case of experience-driven design. In Proceedings of the 2003 international conference on Designing pleasurable products and interfaces (pp. 114-119). ACM.
- Helmi, F., Khaidzir, M., and Bin, K. A. (2016). Analyzing the Critical Role of Sketches in the Visual Transformation of Architectural Design. *ArchNet-IJAR*, 10(2).
- Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, 16(3), 235–266. <http://doi.org/10.1023/B:EDPR.0000034022.16470.f3>
- Ho, S. P., Tserng, H. P., and Jan, S. H. (2013). Enhancing knowledge sharing management using BIM technology in construction. *The Scientific World Journal*.
- Holbrook, J. B. (2013). What is interdisciplinary communication? Reflections on the very idea of disciplinary integration. *Synthese*, 190(11), 1865-1879.
- Holland, R., Wing, S., and Goldberg, D. (2012). Interdisciplinary collaborative bim studio.
- Holste, J. S., and Fields, D. (2010). Trust and tacit knowledge sharing and use. *Journal of knowledge management*, 14(1), 128-140.
- Hong, S. W., Jeong, Y., Kalay, Y. E., Jung, S., and Lee, J. (2016). Enablers and barriers of the multi-user virtual environment for exploratory creativity in architectural design collaboration. *CoDesign*, 12(3), 151-170.
- Hord, S. M. (1986). A synthesis of research on organizational collaboration. *Educational Leadership*, 43(5), 22-26.
- Hoskin, T. (2012). Parametric and nonparametric: Demystifying the terms. In *Mayo Clinic* (pp. 1-5).

- Howells, J. (1996). Tacit knowledge. *Technology analysis and strategic management*, 8(2), 91-106.
- Hung, W., Jonassen, D. H., and Liu, R. (2008). Problem-based learning. *Handbook of research on educational communications and technology*, 3, 485-506.
- Hussein, K. M., and Peña-Mora, F. (1999). Frameworks for interaction support in distributed learning environments. *Journal of Computing in Civil Engineering*, 13(4), 291-302.
- Huxham, C. (Ed.). (1996). *Creating collaborative advantage*. Sage.
- Ibrahim, R. (2005). *Discontinuity in organizations : impacts of knowledge flows on organizational performance* (Doctoral dissertation, University of Stanford).
- Ibrahim, R. and Paulson, B. C. (2008). Discontinuity in organisations: identifying business environments affecting efficiency of knowledge flows in Product Lifecycle Management. *International Journal of Product Lifecycle Management*, 3(1), 21-36.
- Ibrahim, R., and Nissen, M. E. (2005, January). Developing a knowledge-based organizational performance model for discontinuous participatory enterprises. In *System Sciences, 2005. HICSS'05. Proceedings of the 38th Annual Hawaii International Conference on* (pp. 249b-249b). IEEE.
- Ibrahim, R., and Rahimian, F. P. (2010). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978-987.
- Ibrahim, R., and Nissen, M. (2007). Discontinuity in organizations: Developing a knowledge-based organizational performance model for discontinuous membership. *International Journal of Knowledge Management (IJKM)*, 3(1), 10-28.

- Ibrahim, R., and Paulson, B. C. (2008). Discontinuity in organisations: identifying business environments affecting efficiency of knowledge flows in Product Lifecycle Management. *International Journal of Product Lifecycle Management*, 3(1), 21-36.
- Ibrahim, R., Levitt, R. E., and Ramsey, M. (2005). Discontinuity in organizations: Impacts of knowledge flows on organizational performance (Doctoral dissertation, Stanford University).
- Idi, D. B., Khaidzir, K. A. B. M., and Zeari, F. (2011, September). The function of creativity and Innovation in Architectural Design Management. In *International Conference on Construction and Project Management (ICCPM)*, Singapore (Vol. 68).
- Ilhan, B., and Yaman, H. (2016). Green building assessment tool (GBAT) for integrated BIM-based design decisions. *Automation in Construction*.
- Irlwek, M., and Menges, A. (2013, April). Terminological comparison of parametric design processes and Horst Rittel's design methodology. In *Proceedings in GVW-the 1st Global Virtual Conference-Workshop (No. 1)*.
- Isaksson, O., Seppala, S. and Eppinger, S. (2000) Evaluation of design process alternatives using signal flow graphs. *Journal of Engineering Design*, 11, 211–224.
- Isikdag, U. (2012). Design patterns for BIM-based service-oriented architectures. *Automation in Construction*, 25, 59-71.
- Isikdag, U., and Underwood, J. (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction*, 19(5), 544-553.
- Jeng, T. S., and Eastman, C. M. (1998). A database architecture for design collaboration. *Automation in Construction*, 7(6), 475-483.

- Jin, Y. and Chusilp, P. (2006) Study of mental iteration in different design situations. *Design Studies*, 27, 25-55.
- Johansson, P., and Popova, S. (1998). Case-based design process facilitating collaboration and information evolution. In *Artificial Intelligence in Structural Engineering* (pp. 444-448). Springer, Berlin, Heidelberg.
- Joia, L. A., and Lemos, B. (2010). Relevant factors for tacit knowledge transfer within organisations. *Journal of knowledge management*, 14(3), 410-427.
- Jonassen, D. H., and Hung, W. (2008). All problems are not equal: Implications for problem-based learning. *Interdisciplinary Journal of Problem-Based Learning*, 2(2), 4.
- Jonson, B. (2005). "Design ideation: the conceptual sketch in the digital age." *Design Studies* 26(6): 613-624.
- Jutraž, A., and Zupančič, T. (2014). The Role of architect in Interdisciplinary Collaborative Design Studios. *IGRA Ustvarjalnosti (IU)/Creativity Game (CG)–Theory and Practice of Spatial Planning*, 2, 34-42.
- Kahn, K. B. (1996). Interdepartmental integration: a definition with implications for product development performance. *Journal of product innovation management*, 13(2), 137-151.
- Kalay, Y. E. (1998). P3: Computational environment to support design collaboration. *Automation in construction*, 8(1), 37-48.
- Kalay, Y. E. (2001). Enhancing multi-disciplinary collaboration through semantically rich representation. *Automation in Construction*, 10(6), 741-755.
- Kalay, Y. E., Khemlani, L., and Choi, J. W. (1998). An integrated model to support distributed collaborative design of buildings. *Automation in construction*, 7(2), 177-188.

- Kan, J. W. and Gero J. S. (2010). Studying Designers' Behaviour in Collaborative Virtual Workspaces Using Quantitative Methods, *New Frontiers*": the 2010 international conference of CAADRIA (The Association for Computer-Aided Architectural Design Research in Asia).
- Kan, J. W., Bilda, Z., and Gero, J. S. (2006). Comparing entropy measures of idea links in design protocols. In *Design Computing and Cognition'06* (pp. 265-284). Springer, Dordrecht.
- Kan, W. T., and Gero, S. J. (2011). Learning to Collaborate During Team Designing. In *ICORD 11: Proceedings of the 3rd International Conference on Research into Design Engineering*, Bangalore, India, 10.-12.01. 2011.
- Karakaya, A. F., and Şenyapılı, B. (2008). Rehearsal of professional practice: impacts of web-based collaborative learning on the future encounter of different disciplines. *International Journal of Technology and Design Education*, 18(1), 101-117.
- Karnani, F. (2013). The university's unknown knowledge: tacit knowledge, technology transfer and university spin-offs findings from an empirical study based on the theory of knowledge. *The Journal of Technology Transfer*, 38(3), 235-250.
- Kasali, A., and Nersessian, N. J. (2015). Architects in interdisciplinary contexts: Representational practices in healthcare design. *Design Studies*, 41, 205-223.
- Kasimu, A. M. (2014). Knowledge Management in the Civil Engineering Construction Sector in Nigeria (Doctoral dissertation, Universiti Teknologi Malaysia).
- Kerosuo, H. (2015). "BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking." *Procedia Economics and Finance* 21: 201-208
- Ketokivi, M., and Mantere, S. (2010). Two strategies for inductive reasoning in organizational research. *Academy of Management Review*, 35(2), 315-333.

- Khaidzir, K. A. M., and Lawson, B. (2013). The cognitive construct of design conversation. *Research in engineering design*, 24(4), 331-347.
- Khandani, S. (2005) *Engineering Design Process*. Education Transfer Plan. California, IISME Solectron.
- Khemlani, L. (2006). BIM Symposium at the University of Minnesota. *Building the Future (Article) AECbytes*.
- Kiesler, D. J. (1991). Interpersonal methods of assessment and diagnosis. *Handbook of social and clinical psychology: The health perspective*, 438-468.
- Klein, J. T. (2010). A taxonomy of interdisciplinarity. *The Oxford handbook of interdisciplinarity*, 15, 15-30.
- Klein, K. J. (1987). Employee stock ownership and employee attitudes: A test of three models. *Journal of applied psychology*, 72(2), 319.
- Kleinsmann, M. S. (2006). *Understanding collaborative design*.
- Klemmer, S. R., Everitt, K. M., and Landay, J. A. (2008). Integrating physical and digital interactions on walls for fluid design collaboration. *Human-Computer Interaction*, 23(2), 138-213.
- Knotten, V., Svalestuen, F., Hansen, G. K., and Lædre, O. (2015). Design Management in the Building Process-A Review of Current Literature. *Procedia Economics and Finance*, 21, 120-127.
- Kolarevic, B., Schmitt, G., Hirschberg, U., Kurmann, D., and Johnson, B. (2000). An experiment in design collaboration. *Automation in Construction*, 9(1), 73-81.
- Kotlarsky, J., and Oshri, I. (2005). Social ties, knowledge sharing and successful collaboration in globally distributed system development projects. *European Journal of Information Systems*, 14(1), 37-48.

- Krauel, J. (2010). *Inflatable: Shaping Space and Form; Architecture and Design*.
- Kunz, W., and Rittel, H. W. (1970). *Issues as elements of information systems*(Vol. 131). Berkeley, California: Institute of Urban and Regional Development, University of California.
- Kvan, T. (2000). Collaborative design: what is it?. *Automation in construction*, 9(4), 409-415.
- Kvan, T., Vera, A., and West, R. (1997). Expert and situated actions in collaborative design. In *Proceedings of second international workshop on CSCW in design*, International Academic Publishers, Beijing (pp. 400-405).
- Kwon, J., Choi, H., Lee, J., and Chai, Y. (2005). Free-Hand Stroke based NURBS Surface for sketching and Deforming 3D Contents. Paper presented at the PCM 2005, Part I, LNCS 3767.
- Lachman, S. J. (1997). Learning is a process: Toward an improved definition of learning. *Journal of Psychology*, 131, 477-480
- Lahti, H., Seitamaa-Hakkarainen, P., and Hakkarainen, K. (2004). Collaboration patterns in computer supported collaborative designing. *Design Studies*, 25(4), 351-371.
- Laing, R., Leon, M., Mahdjoubi, L., and Scott, J. (2014). Integrating rapid 3D data collection techniques to support BIM design decision making. *Procedia Environmental Sciences*, 22, 120-130.
- Lane, K. (2012). "When is collaboration not collaboration? When it's militarized." *Women Birth* 25(1): 29-38.
- Laseau, P. (2001) *Graphic Thinking for Architects and Designers*, Toronto, John Wiley.

- Lavikka, R., Smeds, M., and Smeds, R. (2012). Towards coordinated BIM based design and construction process. *eWork and eBusiness in Architecture, Engineering and Construction*, 513-520.
- Lawson, B. (1997) *How Designers Think*, Oxford, Architectural Press.
- Lawson, B. (2002) CAD and creativity: does the computer really help? *Leonardo*, 35;3, 327– 331.
- Lawson, B. (2004) *What Designers Know*, London, Architectural press.
- Lawson, B. (2006) *How Designers Think: The Design Process Demystified*, London, Architectural Press.
- Lawson, B. and Loke, S. (1997) Computer Word and Pictures. *Design Studies*, 12.
- Lawson, B. R. (1979). Cognitive strategies in architectural design. *Ergonomics*,22(1), 59-68.
- Lawson, B., and Dorst, K. (2009). *Design expertise*. Architectural Press.
- Lawson, B., and Dorst, K. (2013). *Design expertise*. Routledge.
- Lee, J., and Jeong, Y. (2012). User-centric knowledge representations based on ontology for AEC design collaboration. *Computer-aided design*, 44(8), 735-748.
- Lengel, R. H., and Daft, R. L. (1984). An exploratory analysis of the relationship between media richness and managerial information processing (No. TR-DG-08-ONR). Texas a and M Univ College Station Dept of Management.
- Leon, M., and Toniolo, A. (2015). Analysis of collaborative design and decision making through argumentation applied for pre-BIM stages. *WIT Transactions on The Built Environment*, 149, 217-228.

- Leon, M., Laing, R., Malins, J., and Salman, H. (2015). Making collaboration work: application of a Conceptual Design Stages Protocol for pre-BIM stages. *WIT Transactions on The Built Environment*, 149, 205-216.
- Leonard, D., and Sensiper, S. (1998). The role of tacit knowledge in group innovation. *California management review*, 40(3), 112-132.
- Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strategic management journal*, 13(S1), 111-125.
- Levitt, B., and March, J. G. (1988). Organizational learning. *Annual review of sociology*, 14(1), 319-338.
- Liebowitz, J. (Ed.). (1999). *Knowledge management handbook*. CRC press.
- Lim, B. C., and Klein, K. J. (2006). Team mental models and team performance: A field study of the effects of team mental model similarity and accuracy. *Journal of organizational behavior*, 27(4), 403-418.
- Lin, Y., Su, H. Y., and Chien, S. (2006). A knowledge-enabled procedure for customer relationship management. *Industrial marketing management*, 35(4), 446-456.
- Lloyd, P., Lawson, B., and Scott, P. (1995). Can concurrent verbalization reveal design cognition?. *Design Studies*, 16(2), 237-259.
- Löfgren, J. (2015). Challenges in building information modeling: Insights from a pioneering process development workshop in Finland.
- Lukosch, S., Billingham, M., Alem, L., and Kiyokawa, K. (2015). Collaboration in Augmented Reality. *Computer Supported Cooperative Work (CSCW)*, 24(6), 515-525.
- Lundequist, J. (1998). *Projekteringens teori och metod—en introduktion till design teorin*. KTH, Stockholm.

- Luyten, L. (2015). CAAD and Conceptual Design Collaboration between Architects and Structural Engineers. Real Time-Proceedings of the 33rd eCAADe Conference, Vienna University of Technology.
- Mackay, W. E. (1998). Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers. In Proceedings of the working conference on Advanced visual interfaces (pp. 13-21). ACM.
- MacLeamy, P. (2004). "MacLeamy Curve." Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation (WP-1202).
- Maher L. M., Anna Cicognani, and Simeon Simoff. (1998). "An experimental of computer mediated collaborative design." International Journal of Design Computing 1: 106-114.
- Maher, M. L., Liew, P. S., Gu, N., and Ding, L. (2005). An agent approach to supporting collaborative design in 3D virtual worlds. Automation in Construction, 14(2), 189-195.
- Maher, M., and Tang, H. H. (2003). Co-evolution as a computational and cognitive model of design. Research in Engineering Design, 14(1), 47-64.
- Malaga, R. (2000) The effect of stimulus modes and associative distance in individual creativity support systems. Design Support Systems, Vol 29, 26.
- Mathews, M. (2013). BIM collaboration in student architectural technologist learning. Journal of Engineering, Design and Technology, 11(2), 190-206.
- Mattessich, P. W., and Monsey, B. R. (1992). Collaboration: what makes it work. A review of research literature on factors influencing successful collaboration. Amherst H. Wilder Foundation, 919 Lafond, St. Paul, MN 55104.

- Mazlan, K. S., Khoo, L. M. S., and Jano, Z. (2015). Designing an eportfolio conceptual framework to enhance written communication skills among undergraduate students. *Asian Social Science*, 11(17), 35.
- McCall, R., and Johnson, E. (1997). Using argumentative agents to catalyze and support collaboration in design. *Automation in Construction*, 6(4), 299-309.
- McClure, C. R., and Herson, P. (1991). *Library and Information Science Research: Perspectives and Strategies for Improvement*. Ablex Publishing Corporation, 355 Chestnut Street, Norwood, NJ 07648.
- Mccooy, M. and Evans, G. (2002) The potential role of the physical environment in fostering creativity. *Creativity Research Journal*, Vol 14 No 3and4, 27.
- McDonnell, J. (2012). Accommodating disagreement: A study of effective design collaboration. *Design Studies*, 33(1), 44-63.
- McLean, L. D. (2004). A review and critique of Nonaka and Takeuchi's theory of organizational knowledge creation. In *Proceedings of the Fifth UFHED/AHRD Ireland Conference*. Available: [http://www.mcleanglobal.com/public/MGC/publications/Nonaka% 20and% 20Takeuchi. pdf](http://www.mcleanglobal.com/public/MGC/publications/Nonaka%20and%20Takeuchi.pdf) [accessed May 2014].
- McMillan, J. H., and Schumacher, S. (2010). *Research in Education: Evidence-Based Inquiry*, MyEducationLab Series. Pearson.
- Mehran, D. (2016). Exploring the Adoption of BIM in the UAE Construction Industry for AEC Firms. *Procedia Engineering*, 145, 1110-1118.
- Mendel, J. (2012). A taxonomy of models used in the design process.interactions, 19(1), 81-85.
- Migilinskas, D., Popov, V., Juocevicus, V., and Ustinovichius, L. (2013). The benefits, obstacles and problems of practical BIM implementation. *Procedia Engineering*, 57, 767-774.

- Milliken, F. J., and Martins, L. L. (1996). Searching for common threads: Understanding the multiple effects of diversity in organizational groups. *Academy of management review*, 21(2), 402-433.
- Mitcham, C. (1995). Computers, information and ethics: A review of issues and literature. *Science and Engineering Ethics*, 1(2), 113-132.
- Montoya, M. M., Massey, A. P., Hung, Y. T. C., and Crisp, C. B. (2009). Can you hear me now? Communication in virtual product development teams. *Journal of Product Innovation Management*, 26(2), 139-155.
- Mosley, G., Wright, N., and Wrigley, C. (2018). Facilitating design thinking: A comparison of design expertise. *Thinking Skills and Creativity*.
- Mueller, J. S. (2006). Is your team too big? Too small? What s the right number. *Knowledge@ Wharton*, June, 14.
- Nakayama, T. (1997). The Keisho of development technology: the case of the Japanese aircraft industry. *Journal of Product Innovation Management*, 14(5), 393-405.
- Nathan, M. L., and Mitroff, I. I. (1991). The use of negotiated order theory as a tool for the analysis and development of an interorganizational field. *The Journal of applied behavioral science*, 27(2), 163-180.
- Neghab, A. P., Etienne, A., Kleiner, M., and Roucoules, L. (2015). Performance evaluation of collaboration in the design process: Using interoperability measurement. *Computers in Industry*, 72, 14-26.
- Nikas, A., Poulymenakou, A. and Kriaris P. (2007). "Investigating antecedents and drivers affecting the adoption of collaboration technologies in the construction industry." *Automation in Construction* 16(5): 632-641.
- Nishida, Kitaro. 1921. *An Inquiry into the Good*. Translated by Masao Abe, and Christopher

- Nonaka, I. (1994). "A Dynamic Theory of Organizational Knowledge Creation," *Organization Science* (5:1), pp. 14-37.
- Nonaka, I., and Konno, N. (1998). The concept of "ba": Building a foundation for knowledge creation. *California management review*, 40(3), 40-54.
- Nonaka, I., Konno, N., and Toyama, R. (2001). Emergence of "ba". *Knowledge emergence: Social, technical, and evolutionary dimensions of knowledge creation*, 1, 13-29.
- Nonaka, I., Toyama, R., and Konno, N. (2000). SECI, Ba and leadership: a unified model of dynamic knowledge creation. *Long range planning*, 33(1), 5-34.
- Nonaka, L., Takeuchi, H., and Umemoto, K. (1996). A theory of organizational knowledge creation. *International Journal of Technology Management*, 11(7-8), 833-845.
- Nukala, M., Eppinger, S. and Whitney, D. (1995) *Generalized Models of Design Iteration Using Signal Flow Graphs*. ASME Design Theory and Methodology Conference. Boston MA.
- O'Brien, W., Soibelman, L., and Elvin, G. (2003). Collaborative design processes: an active-and reflective-learning course in multidisciplinary collaboration. *Journal of Construction Education*, 8(2), 78-93.
- Oh, M., Lee, J., Hong, S. W., and Jeong, Y. (2015). Integrated system for BIM-based collaborative design. *Automation in Construction*, 58, 196-206.
- Olatunji, O. A. (2011). Modelling the costs of corporate implementation of building information modelling. *Journal of Financial Management of Property and Construction*, 16(3), 211-231.
- Omanya, W., and Ogara, W. O. (2010). Tacit knowledge transfer.

- Oti, A. H., and Tizani, W. (2015). BIM extension for the sustainability appraisal of conceptual steel design. *Advanced Engineering Informatics*, 29(1), 28-46.
- Oti, A. H., Tizani, W., Abanda, F. H., Jaly-Zada, A., and Tah, J. H. M. (2016). Structural sustainability appraisal in BIM. *Automation in Construction*, 69, 44-58.
- Oxman, R. (2006). Theory and design in the first digital age. *Design studies*, 27(3), 229-265.
- Jonson, B. (2005). Design ideation: the conceptual sketch in the digital age. *Design studies*, 26(6), 613-624.
- Pallant, J. (2001). *SPSS survival manual: A step by step guide to data analysis using SPSS for Windows (versions 10 and 11): SPSS student version 11.0 for Windows*. Milton Keynes: Open University Press.
- Pallasmaa, J. (1996). 2005. *The eyes of the skin. Architecture and the senses*.
- Panahi, S., Watson, J., and Partridge, H. (2013). Towards tacit knowledge sharing over social web tools. *Journal of Knowledge Management*, 17(3), 379-397.
- Papell, C. P., and Skolnik, L. (1992). The reflective practitioner: A contemporary paradigm's relevance for social work education. *Journal of Social Work Education*, 28(1), 18-26.
- Patel, H., Pettitt, M., and Wilson, J. R. (2012). Factors of collaborative working: A framework for a collaboration model. *Applied ergonomics*, 43(1), 1-26.
- Perry, M., and Sanderson, D. (1998). Coordinating joint design work: the role of communication and artefacts. *Design studies*, 19(3), 273-288.
- Pipes, A. (Ed.). (2014). *Computer-Aided Architectural Design Futures*. Butterworth-Heinemann.
- Plume, J., and Mitchell, J. (2007). Collaborative design using a shared IFC building model—Learning from experience. *Automation in Construction*, 16(1), 28-36.

- Polanyi, M. (1962). Tacit knowing: Its bearing on some problems of philosophy. *Reviews of modern physics*, 34(4), 601.
- Polanyi, M. (1966). The logic of tacit inference. *Philosophy*, 41(155), 1-18.
- Polanyi, M. (1967). The tacit dimension. *Knowledge in organizations*, 135-146.
- Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M., and Ali, A. A. A. (2013). Improving dynamic knowledge movements with a knowledge-based framework during conceptual design of a green building project. *International Journal of Knowledge Management (IJKM)*, 9(2), 62-79.
- Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., and Adam, N. M. (2014). A technique to capture multi-disciplinary tacit knowledge during the conceptual design phase of a building project. *Journal of Information and Knowledge Management*, 13(02), 1450013.
- Prats, M., Lim, S., Jowers, I., Garner, S. W., and Chase, S. (2009). Transforming shape in design: observations from studies of sketching. *Design studies*, 30(5), 503-520.
- Preece, J., and Rombach, H. D. (1994). A taxonomy for combining software engineering and human-computer interaction measurement approaches: towards a common framework. *International journal of human-computer studies*, 41(4), 553-583.
- Preece, J., Sharp, H., Rogers, Y. (2015). *Interaction Design-beyond human-computer interaction*. John Wiley and Sons.
- Prigogine, I. (1985). Time and human knowledge. *Environment and Planning B: Planning and Design*, 12(1), 5-20.
- Purcell, T. and Gero, J. (1998) Drawings and the design process. *Design Studies*, Vol 19 No 4, 41.

- Rahimian, F. P. and R. Ibrahim (2011). "Impacts of VR 3D sketching on novice designers' spatial cognition in collaborative conceptual architectural design." *Design Studies* 32(3): 255-291.
- Rahimian, F., Ibrahim, R., and Baharuddin, M. N. (2008) Using IT/ICT as a new medium toward implementation of interactive architectural communication cultures, *International Symposium on Information Technology*, Kuala Lumpur Convention Centre, Malaysia, IEEE.
- Rahman, N., Cheng, R., and Bayerl, P. S. (2013). Synchronous versus asynchronous manipulation of 2D-objects in distributed design collaborations: Implications for the support of distributed team processes. *Design Studies*, 34(3), 406-431.
- Ren, Z., Yang, F., Bouchlaghem, N. M., and Anumba, C. J. (2011). Multi-disciplinary collaborative building design—A comparative study between multi-agent systems and multi-disciplinary optimisation approaches. *Automation in Construction*, 20(5), 537-549.
- RIBA (2013). *Plan of Work 2013 overview*. London: Royal Institute of British Architects.
- Ringelmann, M. (1913) "Recherches sur les moteurs animés: Travail de l'homme" [Research on animate sources of power: The work of man], *Annales de l'Institut National Agronomique*, 2nd series, vol. 12, pages 1-40. Available online (in French) at: <http://gallica.bnf.fr/ark:/12148/bpt6k54409695.image.f14.langEN>.
- Robbins, E. (1994) *Why Architects Draw.*, Cambridge, MIT Press.
- Robbins, R. W. (2001). *Facilitating intelligent media space collaboration via RASCAL: The reflectively adaptive synchronous coordination architectural framework*. University of Ottawa (Canada).
- Robert, L. P., and Dennis, A. R. (2005). Paradox of richness: A cognitive model of media choice. *IEEE transactions on professional communication*, 48(1), 10-21.

- Robillard, P. N., d'Astous, P., Détienne, F., and Visser, W. (1998, April). Measuring cognitive activities in software engineering. In *Software Engineering, 1998. Proceedings of the 1998 International Conference on* (pp. 292-300). IEEE.
- Rogers, Y., Lim, Y. K., Hazlewood, W. R., and Marshall, P. (2009). Equal opportunities: Do shareable interfaces promote more group participation than single user displays?. *Human-Computer Interaction*, 24(1-2), 79-116.
- Roschelle, J., and Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In *Computer supported collaborative learning* (pp. 69-97). Springer, Berlin, Heidelberg.
- Rosenman, M. A., Smith, G., Maher, M. L., Ding, L., and Marchant, D. (2007). Multidisciplinary collaborative design in virtual environments. *Automation in Construction*, 16(1), 37-44.
- Rosenman, M., and Wang, F. (2001). A component agent based open CAD system for collaborative design. *Automation in Construction*, 10(4), 383-397.
- Rothbard, A. T. (1998). How to keep employees. *Journal of Management in Engineering*, 14(4), 21-22.
- Rowe, P. G. (1987). *Design Thinking* MIT Press. Cambridge, MA, 28.
- Rowland, G. (1993). Designing and instructional design. *Educational technology research and development*, 41(1), 79-91.
- Rowley, J. 2007. The wisdom hierarchy: representations of the DIKW hierarchy. *Journal of Information Science*, 33, 163-180
- Sabherwal, R., and Sabherwal, S. (2007). How do knowledge management announcements affect firm value? A study of firms pursuing different business strategies. *IEEE Transactions on Engineering Management*, 54(3), 409-422.

- Safoutin, M. J. (2003). A methodology for empirical measurement of iteration in engineering design processes (Doctoral dissertation, University of Washington).
- Sailer, I., Gottner, J., Känel, S., and Franz Hämmerle, C. H. (2009). Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. *International Journal of Prosthodontics*, 22(6), 553.
- Sanchez, R., and Mahoney, J. T. (1996). Modularity, flexibility, and knowledge management in product and organization design. *Strategic management journal*, 17(S2), 63-76.
- Sanguinetti, P., Abdelmohsen, S., Lee, J., Lee, J., Sheward, H., and Eastman, C. (2012). General system architecture for BIM: An integrated approach for design and analysis. *Advanced Engineering Informatics*, 26(2), 317-333.
- Saunders, M. N., Lewis, P., Thornhill, A., and Bristow, A. (2015). Understanding research philosophy and approaches to theory development.
- Schmidt, D. C., Stal, M., Rohnert, H., and Buschmann, F. (2013). *Pattern-Oriented Software Architecture, Patterns for Concurrent and Networked Objects (Vol. 2)*. John Wiley and Sons.
- Schmidt, M., Pedersen, L., and Sørensen, H. T. (2014). The Danish Civil Registration System as a tool in epidemiology. *European journal of epidemiology*, 29(8), 541-549.
- Schmitt, G. (1998). A new collaborative design environment for engineers and architects. In *Artificial Intelligence in Structural Engineering* (pp. 384-397). Springer, Berlin, Heidelberg.
- Schön, D. (1983) *The Reflective Practitioner: How Professionals Think in Action*, London., Basic Books.

- Schön, D. A. (1984). The architectural studio as an exemplar of education for reflection-in-action. *Journal of Architectural Education*, 38(1), 2-9.
- Schön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. Jossey-Bass.
- Schön, D. A. (Ed.). (1991). *The reflective turn: Case studies in and on educational practice*. Teachers College Press.
- Scruton, R. (1979) *The Aesthetic of Architecture*, Princeton, Princeton university press.
- Seidler-de Alwis, R., and Hartmann, E. (2008). The use of tacit knowledge within innovative companies: knowledge management in innovative enterprises. *Journal of knowledge Management*, 12(1), 133-147.
- Selsky, J. W., and Parker, B. (2005). Cross-sector partnerships to address social issues: Challenges to theory and practice. *Journal of management*, 31(6), 849-873.
- Senker J. 1993. The contribution of tacit knowledge to innovation. *AI and Society* 7: 208–224.
- Senker, J. (2016). Tacit Knowledge to. *Exploring Expertise: Issues and Perspectives*, 223.
- Seol, U. H., Bae, B. H., Park, J. S., Shin, J. C., and Lee, G. I. (2014). Analysis of Reliability and Suggestion on BIM design at Daegu Expressway Lot No. 5. *Journal of KIBIM*, 4(4), 1-12.
- Sharfman, M. P., and Dean Jr, J. W. (1991). Conceptualizing and measuring the organizational environment: A multidimensional approach. *Journal of management*, 17(4), 681-700.
- Shen, W., Hao, Q., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., ... and Xue, H. (2010). *Systems integration and collaboration in architecture, engineering,*

construction, and facilities management: A review. *Advanced engineering informatics*, 24(2), 196-207.

Shimizu, Hiroshi. 1995. "Ba-Principle: New Logic for the Real-Time Emergence of

Simmel, G. (1950). The dyad and the triad. *The Sociology of Georg Simmel*, 59-68.

Simoff, S. J., and Maher, M. L. (1997). Design education via web-based virtual environments. In *Computing in Civil Engineering, Proceedings of the Fourth Congress of Computing in Civil Engineering*, ASCE, NY (pp. 418-425).

Simoff, S. J., and Maher, M. L. (2000). Analysing participation in collaborative design environments. *Design studies*, 21(2), 119-144.

Simon, D. P., and Simon, H. A. (1978). Individual differences in solving physics problems.

Simon, H. (1969) *The Sciences of the Artificial*, Cambridge, MA, MIT Press.

Singh, V., Gu, N., and Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, 20(2), 134-144.

Skopp, N. A., Workman, D. E., Adler, J. L., and Gahm, G. A. (2015). Analysis of Distance Collaboration Modalities: Alternatives to Meeting Face-to-Face. *International Journal of Human-Computer Interaction*, 31(12), 901-910.

Snyder, M. (1984). When belief creates reality. *Advances in experimental social psychology*, 18, 247-305.

Sobol, M. G., and Lei, D. (1994). Environment, manufacturing technology, and embedded knowledge. *International Journal of Human Factors in Manufacturing*, 4(2), 167-189.

- Sonnenwald, D. H. (1996). Communication roles that support collaboration during the design process. *Design studies*, 17(3), 277-301.
- Sproull, L., and Kiesler, S. (1991). *New ways of working in the networked organization*. Cambridge, MA.
- Stahl, G. (2002). *Computer Support for Collaborative Learning: Foundations for a CscI Community (CscI 2002 Proceedings)*. Psychology Press.
- Stahl, G. (2006). Scripting group cognition: The problem of guiding situated collaboration. *Scripting computer-supported collaborative learning: Cognitive, computational and educational perspectives*, 327-335.
- Stauffer, L. and Ullman, D. (1991) *Fundamental Processes of Mechanical Designers Based on Empirical research*.
- Stempfle, J., and Badke-Schaub, P. (2002). Thinking in design teams-an analysis of team communication. *Design studies*, 23(5), 473-496.
- Stones, C. and T. Cassidy (2010). "Seeing and discovering: how do student designers reinterpret sketches and digital marks during graphic design ideation?" *Design Studies* 31(5): 439-460.
- Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in construction*, 18(3), 357-375.
- Succar, B., and Kassem, M. (2015). Macro-BIM adoption: Conceptual structures. *Automation in Construction*, 57, 64-79.
- Suddaby, R. (2006). From the editors: What grounded theory is not.
- Suwa, M. and Tversky, B. (1997) What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*, 18, 18.

- Suwa, M., Tversky, B., Gero, J., and Purcell, T. (2001). Seeing into sketches: Regrouping parts encourages new interpretations. In *Visual and spatial reasoning in design* (pp. 207-219).
- Tamer Cavusgil, S., Calantone, R. J., and Zhao, Y. (2003). Tacit knowledge transfer and firm innovation capability. *Journal of business and industrial marketing*, 18(1), 6-21.
- Tang, H., Lee, Y. and Gero, J. (2010) Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies*, 32, 1-29.
- Tang, M. X., and Frazer, J. (2001). A representation of context for computer supported collaborative design. *Automation in Construction*, 10(6), 715-729.
- Taylor, R. B., De Soto, C. B., and Lieb, R. (1979). Sharing secrets: Disclosure and discretion in dyads and triads. *Journal of Personality and Social Psychology*, 37(7), 1196.
- Thrift, N., and French, S. (2002). The automatic production of space. *Transactions of the Institute of British Geographers*, 27(3), 309-335.
- Tully, C. (1986) *Software Process Models and Iteration; Iteration in the Software Process*. Third International Software Process Workshop IEEE.
- Uluoğlu, B. (2000). Design knowledge communicated in studio critiques. *Design Studies*, 21(1), 33-58.
- Uzzi, B., and Spiro, J. (2005). Collaboration and creativity: The small world problem. *American journal of sociology*, 111(2), 447-504.
- Vaishnavi, V. K., and Kuechler, W. (2015). *Design science research methods and patterns: innovating information and communication technology*. Crc Press.

- Valkenburg, R. and K. Dorst (1998). "The reflective practice of design teams." *Design Studies* 19(3): 249-271.
- Van Maanen, John, Jesper B. Sørensen, and Terence R. Mitchell. "The interplay between theory and method." *Academy of management review* 32.4 (2007): 1145-1154.
- Vasconcelos, J., Kimble, C., Gouveia, F., and Kudenko, D. (2000, October). A group memory system for corporate knowledge management: an ontological approach. In *Proceedings of the 1st European Conference on Knowledge Management (ECKM'2000)* Bled School of Management, Slovenia (pp. 91-99).
- Veeramani, D., Tserng, H. P., and Russell, J. S. (1998). Computer-integrated collaborative design and operation in the construction industry. *Automation in Construction*, 7(6), 485-492.
- Vera, A. H., Kvan, T., West, R. L., and Lai, S. (1998, January). Expertise, collaboration and bandwidth. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 503-510). ACM Press/Addison-Wesley Publishing Co.
- Visser, W. (1995). Use of episodic knowledge and information in design problem solving. *Design Studies*, 16(2), 171-187.
- Vysotskiy, A., Makarov, S., Zolotova, J., and Tuchkevich, E. (2015). Features of BIM Implementation Using Autodesk Software. *Procedia Engineering*, 117, 1148-1157.
- Wang, J., Chong, H. Y., Shou, W., Wang, X., and Guo, J. (2014). BIM-Enabled Design Collaboration for Complex Building. In *International Conference on Cooperative Design, Visualization and Engineering* (pp. 238-244). Springer International Publishing.

- Wang, X. and P. S. Dunston (2008). "User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review." *Automation in Construction* 17(4): 399-412.
- Wang, X., and Dunston, P. S. (2013). Tangible mixed reality for remote design review: a study understanding user perception and acceptance. *Visualization in Engineering*, 1(1), 8.
- Wang, X., Kim, M. J., Love, P. E. and Kang, S. C. (2013). Augmented Reality in built environment: Classification and implications for future research. *Automation in Construction*, 32, 1-13.
- Wang, X., Love, P. E., Kim, M. J., Park, C. S., Sing, C. P. and Hou, L. (2013). A conceptual framework for integrating building information modeling with augmented reality. *Automation in Construction*, 34, 37-44.
- Webb, M. and Gibson, D. (2015). Technology enhanced assessment in complex collaborative settings. *Education and Information Technologies*, 20(4), 675-695.
- Wetzel, E. M. and Thabet, W. Y. (2015). The use of a BIM-based framework to support safe facility management processes. *Automation in Construction*, 60, 12-24.
- Whitbeck, C. (1998). *Engineering ethics in practice and research*.
- Wickes, M., Leslie, A., Lettice, F., Feeney, A., and Everson, P. (2003). A Perspective of Nonaka's SECI Model from Programme Management: Combining Management Information, Performance Measurement and Information Design. In 4th Conference on Organisational Knowledge, Learning and Capabilities (OKLC), Barcelona (pp. 1-18).
- Wiegeraad, S. (1999), "Development of a design history system", PhD thesis, Stan Ackermans

- Wijnen, W. H. F. W. (2000). Towards design-based learning. Eindhoven: Eindhoven University of Technology.
- Wiltchnig, S., Christensen, B. T. and Ball, L. J. (2013). Collaborative problem–solution co-evolution in creative design. *Design Studies*, 34(5), 515-542.
- Wittenberg-Lyles, E. M. (2005). Information sharing in interdisciplinary team meetings: An evaluation of hospice goals. *Qualitative Health Research*, 15(10), 1377-1391.
- Won, J. and Lee, G. (2016). How to tell if a BIM project is successful: A goal-driven approach. *Automation in Construction*, 69, 34-43.
- Wong, K. D. and Fan, Q. (2013). Building information modelling (BIM) for sustainable building design. *Facilities*, 31(3/4), 138-157.
- Woo, S., Lee, E., and Sasada, T. (2001). The multiuser workspace as the medium for communication in collaborative design. *Automation in Construction*, 10(3), 303-308.
- Wood, D. J., and Gray, B. (1991). Toward a comprehensive theory of collaboration. *The Journal of Applied Behavioral Science*, 27(2), 139-162.
- Wynn, D., Claudia, E. and John, C. (2007) Modeling Iteration In Engineering Design. International Conference On Engineering Design, ICED'07. Paris, France.
- Xue, X., Shen, Q., Fan, H., Li, H. and Fan, S. (2012). IT supported collaborative work in A/E/C projects: A ten-year review. *Automation in Construction*, 21, 1-9.
- Yamauchi, Y. (2014). User knowledge transformation through design: A historical materialism perspective. *Information and Organization*, 24(4), 270-290.
- Yan-chuen, L., Phil, M., and Gilleard, J. D. (2000). Refurbishment of building services engineering systems under a collaborative design environment. *Automation in construction*, 9(2), 185-196.

Yoshimichi, A. D. A. C. H. I. (2011). An Examination of the SECI Model in Nonaka's Theory in terms of the TEAM Linguistic Framework. *Yamanashi Glocal Studies: Bulletin of Glocal Policy Management and Communication*, 6, 21-33.

Zolin, R., Hinds, P. J., Fruchter, R., and Levitt, R. E. (2004). Interpersonal trust in cross-functional, geographically distributed work: A longitudinal study. *Information and Organization*, 14(1), 1-26.

Zumthor, P. (2006a). *Peter Zumthor: Atmospheres*. Birkhäuser.

Zumthor, P. (2006b). *Publishers for Architecture*. Basel, Boston, Berlin.