



Cairo University

INTEGRATING BIM IN SUSTAINABLE DESIGN FOR SOLAR POWER DESIGN WITH EMPHASIS ON PV DESIGN

By

BASSANT MOHAMED NABIL ABD EL MAGEED

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In
ARCHITECTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

**INTEGRATING BIM IN SUSTAINABLE DESIGN FOR
SOLAR POWER DESIGN
WITH EMPHASIS ON PV DESIGN**

By

BASSANT MOHAMED NABIL ABD EL MAGEED

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In

ARCHITECTURAL ENGINEERING

Under the Supervision of

Prof. Dr. Ayman Hassan Ahmed

Professor of Landscape Design
Architecture Department
Faculty of Engineering,
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

INTEGRATING BIM IN SUSTAINABLE DESIGN FOR SOLAR POWER DESIGN WITH EMPHASIS ON PV DESIGN

By

BASSANT MOHAMED NABIL ABD EL MAGEED

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In

ARCHITECTURAL ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Ayman Hassan Ahmed, Thesis Main Advisor

Professor of Landscape Design, Architecture Department, Faculty of Engineering, Cairo University

Prof. Dr. Ahmed Ahmed Fekry, Internal Examiner

Professor of Architecture, Architecture Department, Faculty of Engineering, Cairo University

Prof. Dr. Abbas El – Zafarany, External Examiner

Professor Dean of the Faculty of Urban and Regional Planning, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

Engineer: Bassant Mohamed Nabil Abd El Mageed

Date of Birth: 27/06/1989

Nationality: Egyptian

E-mail: bassantmohamednabil-239@hotmail.com

Phone.: 01009603579

Address: 25 El Kordi St, Espates, El-Haram, Giza

Registration Date: 01 / 03 / 2012

Awarding Date: / / 2019

Degree: Master of science

Department: Architectural Engineering

Supervisors: Prof. Dr. Ayman Hassan Ahmed

Examiners: Prof. Dr. Ayman Hassan Ahmed (Thesis Main Advisor)

Prof. Dr. Ahmed Ahmed Fekry (Internal Examiner)

Prof. Dr. Abbas El – Zaafarany (External Examiner)

Title of Thesis: Integrating BIM In Sustainable Design for Solar Power
with Emphasis on PV Design

Key Words: BIM (Building Information Modeling); Sustainable
architecture; Renewable Energy; Solar Energy; PV; BIPV

Summary:

The purpose of this thesis is to highlight the effect of using BIM through design possibilities regarding the solar technologies for sustainable design with emphasis on building integrated photovoltaic system using solar energy to generate electricity. Thesis methodology is based on a literature review of the last decade researches in Sustainable BIM integration by using BIM tools for BPS process with the emphasis of BIPV energy simulation. The Literature review revealed that integrating BIM in sustainable design done through IFC and gbXML open BIM formats which have a lot of interoperability issues while exporting BIM models to building performance analysis tools. The objective of the thesis is to integrate BIM in sustainable design using BPS BIM-based tools and avoiding the mentioned interoperability issues faced the users in the last decade. In order to accomplish this objective, we have used the same platform BPS BIM-based tools to avoid interoperability issues while exporting models to the open BIM formats such as IFC. The results accentuate that using same platform tools avoid all interoperability issues and achieves seamless BIPV simulation.



Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the reference section.

Name:

Date:

Signature:

Acknowledgments

First, I thank Allah the most gracious and the most merciful for guiding me and blessing me with patience and knowledge to finish this work.

I would like to express my sincere gratitude to Prof. Dr. Ayman Hassan, Professor of Landscape Design, Architecture Department, Faculty of Engineering, Cairo University, for the continuous support of my master study and research, his supervision, his patience, motivation, enthusiasm, professional knowledge and the useful comments and remarks that had strengthened this work.

I would like to thank my parents, who have supported me during this work.

Last but not least I would like to express my gratitude to KEMET Corporation for all practical experience I have gained during working there and for facilitating all software I have learned and worked with, and special thanks to Eng. Mohamed EL Yamani for that.

Table of Contents

Disclaimer	I
Acknowledgments.....	II
Table of Contents.....	III
LIST OF TABLES AND FIGURES.....	VII
NOMENCLATURE	XI
ABSTRACT.....	XII
RESEARCH PROBLEM.....	XIII
RESEARCH OBJECTIVES	XIV
RESEARCH QUESTION.....	XV
RESEARCH METHODOLOGY.....	XV
CHAPTER 01 SOLAR ENERGY IN EGYPT	1
1.1 Overview	2
1.2. Egypt solar energy potential.....	2
1.2.1. Types of Irradiations	2
Global Horizontal Irradiation.....	3
Direct Normal Irradiation	4
1.3. Initiatives of developing solar energy	5
1.4. Solar Energy challenges	7
1.4.1. Economic and financial challenges:.....	7
1.4.2 Governance challenges	7
1.4.3. Technical challenges.....	7
1.4.4. Other challenges.....	7
1.5. Solar Energy Strategies for addressing challenges	8
1.5.1. Financial and Economic Strategies.....	8
1.5.2. Organizational strategies.....	8
1.5.3. Urgent strategies Technical constraints	8
1.6. Egypt solar energy future	8
1.6.1. Executive Plan (2015/2016-2025/2026)	8
1.7. Photovoltaic in Egypt.....	9
1.7.1. Photovoltaic Power Potential.....	10
1.8. Solar Photovoltaic (PV) technology.....	11
1.8.1. Solar Photovoltaics types.....	11
1.8.2. PV system configurations	12

1.8.3.	PV system Design Consideration.....	16
1.8.4.	Integration of Photovoltaics in Architecture.....	19
	Building Applied Photovoltaics (BAPV).....	20
	Building Integrated Photovoltaics (BIPV).....	20
	Comparative Review.....	26
CHAPTER 02 BIM IMPLEMENTATION IN SUSTAINABLE DESIGN.....		28
2.1.	Sustainable Architecture	29
2.1.1.	Overview.....	29
2.1.2.	The Principles of Sustainable architecture.....	29
2.2.	Passive and Active Design	30
2.2.1.	Passive Design:	30
2.2.2.	Active Design:	30
2.3.	BIM In Sustainable Design	31
2.3.1.	BIM Definition.....	31
2.3.2.	BIM Risks	31
2.3.3.	BIM Success Factors.....	31
2.3.4.	Contribution of BIM to Sustainable Design	32
	2.3.4.1. Integrated Project Delivery (IPD).....	32
	2.3.4.2. Design optimization.....	32
2.3.5.	The Benefits of Using BIM in Sustainable Architecture	33
2.4.	BIM Implementation strategy	34
2.4.1.	BIM USES	35
	2.4.1.1. Objectives	37
	2.4.1.2. Characteristics	38
2.4.2.	BIM Execution Process.....	39
2.4.3.	Information Exchanges	42
	2.4.3.1. Level of Development	42
2.4.4.	Infrastructure for BIM Implementation	43
	2.4.4.1. BIM Project Execution Plan Overview	44
	2.4.4.2. Project Information.....	44
	2.4.4.3. Key project contacts	44
	2.4.4.4. Organizational Roles and Staffing.....	44
	2.4.4.5. BIM and Facility Data Requirements.....	44
	2.4.4.6. Collaboration Procedures	45
	2.4.4.7. Quality Control	45

2.4.4.8.	Technology Infrastructure Needs	45
2.4.4.9.	Model Structure	45
2.4.4.10.	Project Deliverables	45
2.4.4.11.	Delivery Strategy / Contract.....	45
CHAPTER 03 LITERATURE REVIEW		46
3.1.	Building Performance Simulation “Energy Analysis”	46
3.2.	Building Performance simulation software.....	47
3.2.1.	Building Energy models (BEM)	48
3.3.	BIM and Building Performance Analysis Integration.....	49
3.3.1.	BIM-BPS Data Exchange	50
3.3.1.1.	Software development schemas.....	50
3.3.2.	IFC and gbXML Comparative review	55
	Level of Development (LOD)	57
3.3.3.	Categories of Simulation Tools	58
3.3.3.1.	Design Tools Plug-Ins	58
	GUI’s Based on Simulation Engines	63
3.3.3.2.	Standalone Simulation Tool	64
3.3.4.	BIM-Based Solar PV modeling and simulation.....	64
3.3.5.	Information Management.....	70
3.3.6.	IDM/MVD Methodology.....	70
3.3.6.1.	Prepare/adjust BIM (BIM Creation).....	70
3.3.6.2.	Information Delivery Manual (IDM)	75
3.3.6.3.	The Model View Definition (MVD)	81
3.4.	Problems and challenges	84
3.4.1.	Problems	84
	Project phases.....	84
	Accuracy or uncertainty	84
	Complexity.....	85
3.4.2.	Challenges.....	86
3.4.2.1.	Challenge 01 Building Conceptual Modeling	86
3.4.2.2.	Challenge 02 Building Construction and Development	87
3.4.2.3.	Challenge 03 Quality Assurance	87
3.4.2.4.	Challenge 04 Modeling Weather and Climate Scenarios.....	88
3.4.2.5.	Challenge 05 Modeling Occupant Behavior	89
3.4.2.6.	Challenge 06 Expanding BPS Tools Capabilities by Software Coupling ..	89

3.4.2.7.	Challenge 07 Applying BPS-Based Optimization in Design Practice	90
3.4.2.8.	Challenge 08 Expanding BPS Potential Through BIM.....	90
3.4.2.9.	Challenge 09 Visualization and Communication Skills of BPS Tools	91
3.4.2.10.	Challenge 10 Selection of Suitable BPS Tools	91
3.5.	Conclusion.....	91
3.6.	Recommendations	92
CHAPTER 04 CASE STUDY		96
4.1.	Objective	96
4.2.	Methodology	96
4.2.1.	BIM Use and goals	97
4.2.2.	Process Map.....	97
4.2.3.	Information Exchange	99
4.2.4.	Supporting Infrastructure.....	99
4.2.4.1.	Project Information	99
4.2.4.2.	BIM Tools/Software	100
	Autodesk Insight 360	100
	Autodesk FormIt	101
	Autodesk Revit.....	103
	Autodesk Dynamo	105
4.2.2.	Procedures	107
	Conceptual analysis (Site Potentials).....	107
	Conceptual Design Phase.....	121
	Detailed Design (DD) Phase	122
4.2.3.	Results	131
4.2.3.1.	Site Potentials Results.....	131
4.2.3.2.	Detailed Design Results	133
CHAPTER 05 CONCLUSION AND FUTURE WORK		134
5.1.	Discussion	134
5.2.	Findings.....	135
5.3.	Conclusion.....	135
	Recommendations	136
5.4.	Future work	139
REFERENCES		140

LIST OF TABLES AND FIGURES

Figure 1: Electric power consumption	Figure 2: Energy consumption in Egypt.....	XIII
Figure 3: BIM integrated in Sustainable design (Amarnath CB ,2017)		XIV
Figure 4: Methodology concept		XV
Figure 5: Average rates of primary energy sources in the production of electricity		1
Figure 6: Egypt's electricity consumption growth rate.....		1
Figure 7: Egypt annual average of direct solar irradiation		2
Figure 8: Types of Irradiations (Zell et al., 2015).....		3
Figure 9: Egypt Average Daily/Yearly Sum of GHI (Globalsolaratlas.info, 2018)		4
Figure 10: Egypt averages daily/yearly sum of DNI (Globalsolaratlas.info, 2018)		5
Figure 11: Renewable energy Percentages by 2035 (Iea.org, 2018)		6
Figure 12: PV Current status (Egyptian's PV Solar Energy, 2015)		9
Figure 13: Market Forecasts for the cumulative renewable energy technologies		9
Figure 14: Egypt average daily/yearly sum of electricity production from a 1KW-peak grid-connected solar PV power plant (Globalsolaratlas.info, 2018)		10
Figure 15: Solar Photovoltaic operating principle		11
Figure 16: Photovoltaics types.....		11
Figure 17: PV system taxonomy chart.....		12
Figure 18: On-Grid PV system diagram		13
Figure 19: Off-Grid PV system diagram		13
Figure 20: Off-Grid DC system simplified diagram.....		14
Figure 21: Off-Grid AC system simplified diagram.....		14
Figure 22: Hybrid system simplified diagram		15
Figure 23: Micro-Grid System simplified diagram		15
Figure 24: Site analysis.....		16
Figure 25: World distribution of the annual solar radiation		16
Figure 26: PV orientation and tilt options.....		17
Figure 27: PV system shading losses.....		17
Figure 28: Weather effect on photovoltaics.....		18
Figure 29: Photovoltaics Maintenance.....		18
Figure 30: BAPV system		20
Figure 31: BIPV cell types and cell distance		21
Figure 32: BIPV facades degree of transparency		21
Figure 33: BIPV Curtain system Details		22
Figure 34: Solar Solutions Glazing Options		22
Figure 35: BIPV facades_ CIB Bank Smart Village		23
Figure 36: BIPV External devices		23
Figure 37: BIPV in-roof mounting system Steel trough.....		24
Figure 38: BIPV Fully integrated roof.....		24
Figure 39: BIPV Solar Roof Shingles Anatomy		24
Figure 40: BIPV Solar Roof Shingles Types.....		25
Figure 41: BIPV Membrane.....		25
Figure 42: BIPV Metal Roof Panels		26
Figure 43: Egypt Energy consumption (Gail Tverberg,2017)		28
Figure 44: Elements of green building design (USGBC,2002).		29

Figure 45: BIM Success at the confluence of three constituent parts.....	31
Figure 46:” MacLeamy Curve” Patrick MacLeamy CEO	33
Figure 47: Implementation strategy	34
Figure 48: The Components of a BIM Use (KREIDER AND MESSNER,2013).....	35
Figure 49: Objectives.....	37
Figure 50: Project Phases.....	38
Figure 51: Notation for a Process in the Process Map.....	39
Figure 52: BIM Execution Planning Process Map Overall	40
Figure 53:Detailed BIM Use (Energy Analysis) Process Map.....	41
Figure 54: Level of developments and information eLOD - iLOD	43
Figure 55: Dynamic interacting sub-systems (Hensen et al., 2004).	47
Figure 56: Energy model workflow (Fassbender, 2014).	48
Figure 57: The hierarchy of the gbXML document information (Gupta, 2013).	51
Figure 58: The Plain Text content of a STEP File (buildingSMART, 2012).	53
Figure 59: IFC Schema content (Muñoz, 2016).	54
Figure 60: BIM—IFC data exchange process (Muñoz, 2016).	54
Figure 61: BIM to BPS two different workflows Figure 62: Case study models	55
Figure 63: LOD map for BPS process (Aksamija, 2012)	58
Figure 64: framework of simulation plugins for design tools (Han et al., 2018)	59
Figure 65: Modified Framework of Simulation Plug-Ins for Design Tools (The Researcher).....	59
Figure 66: BIM Compatible Solar PV Modeling Work Flow Diagram (Gupta, Rezgui and Hopfe, 2012).	68
Figure 67:IDM/MVD Process.....	70
Figure 68: BIM Preparation Process for Energy Analysis.....	71
Figure 69: IDM Components	76
Figure 70: The IDM process map for energy analysis in conceptual design stage example ...	77
Figure 71: Functional parts in an exchange requirement.....	81
Figure 72: Simulation Tools Input Data	82
Figure 73: 3D Model Objects of “IfcElement” (Alshehri et al., 2017).....	83
Figure 74: BIM Export BPS process	84
Figure 75: BIM to BPS model inaccuracies	85
Figure 76: gbXML model element definition.....	85
Figure 77: IFC model element definition.....	85
Figure 78: Diagram identifying the main phases and activities of the BPS process	86
Figure 79:Interface between an optimization program and a generic BPS program	90
Figure 80: Case Study Detailed Use Process Map.....	98
Figure 81: Insight 360 tools on the Analyze tab in Revit	101
Figure 82:Insight 360 tools on FormIt tab	101
Figure 83: FormIt Interface.....	102
Figure 84: Revit Interface	103
Figure 85: Dynamo Interface	106
Figure 86: FormIt Location setting.....	108
Figure 87:FormIt generic forms simulation alternative 01	108
Figure 88: FormIt generic forms simulation alternative 02	109
Figure 89: Revit Location setting	109
Figure 90: Tilt mass roof-1	110

Figure 91: Tilt mass roofs- 2.....	110
Figure 92: Flat surface roof.....	111
Figure 93: latitude tilt roof.....	111
Figure 94: Tilt Angle 30 degrees, location Aswan	112
Figure 95: Tilt Angle 24 degrees, location Aswan	113
Figure 96: Tilt Angle 15 degrees, location Aswan	113
Figure 97: Tilt Angle 5 degrees, location Aswan	114
Figure 98: Tilt Angle 30 degrees, location Cairo	115
Figure 99: Tilt Angle 25 degrees, location Cairo	115
Figure 100: Tilt Angle 15 degrees, location Cairo	116
Figure 101: Tilt Angle 5 degrees, location Cairo	116
Figure 102: South orientation, Location Aswan	117
Figure 103: 10 degrees South West orientation, Location Aswan.....	118
Figure 104: 20 degrees South West orientation, Location Aswan.....	118
Figure 105: 30 degrees South West orientation, Location Aswan.....	119
Figure 106: 45 degrees South West orientation, Location Aswan.....	119
Figure 107: 60 degrees South West orientation, Location Aswan.....	120
Figure 108: 75 degrees South West orientation, Location Aswan.....	120
Figure 109: FormIt – Insight 360 interface.....	121
Figure 110: Initial project view in Insight 360	122
Figure 111: Dynamo nodes created for PV parameters	126
Figure 112: Parameters sliders and nodes.....	126
Figure 113: Revit Selection Surface	127
Figure 114: Second roof surface Revit selection	129
Figure 115: Optimum Tilt Angle comparison between Aswan and Cairo	132
Figure 116: Optimum orientation angle in Aswan chart	132
Figure 117: Result for optimum roof PV arrays	133
Figure 118: Result for optimum roof PV arrays	133
Figure 119: BIM success factors.....	135

Table 1: Types of Irradiations (Zell et al., 2015).....	3
Table 2: Photovoltaics Characteristics.....	12
Table 3: BIPV and BAPV Comparative review	26
Table 4: BIPV forms comparative review	27
Table 5:BIM Uses Purposes and Objectives (KREIDER AND MESSNER,2013).....	35
Table 6: BIM Use Characteristics (KREIDER AND MESSNER,2013).....	36
Table 7: Process Mapping Notation for BIM Process Maps	39
Table 8: LOD Definitions	42
Table 9: BEP Supporting Infrastructure information.....	43
Table 10: Critical Project Overview Information	44
Table 11: Most commonly used schemas neutral formats comparison	50
Table 12: The types of open standards developed by buildingSMART	52
Table 13: IFC Data File Formats and Icons.....	52
Table 14: Comparison of extracted IFC and gbXML data (Ivanova, Kiesel and Mahdavi, 2015)	56
Table 15:Comparison of processed IFC and gbXML data (Ivanova, Kiesel and Mahdavi, 2015)	56
Table 16:Level of development for BEM parameters during building design (Gerrish et al., 2017).	57
Table 17: OpenStudio features.....	60
Table 18: Heat Transfer in Building version 2 (HTB2) features	60
Table 19: Sefaria features	61
Table 20: IES VE features	61
Table 21: Green Building Studio (GBS) features	61
Table 22: Ladybug Features.....	62
Table 23: Honeybee Features.....	62
Table 24: DIVA Features.....	63
Table 25:The lists for some BPS tools and third-party BPS tools.....	63
Table 26: list of PV solar design tools (Jakica, 2018)	65
Table 27: Solar PV design tools comparison (Jakica, 2018).	66
Table 28: Solar PV design tools comparison (Jakica, 2018).	67
Table 29: Information for the PV simulation.....	69
Table 30: Exchange requirements BIM to energy analysis	82
Table 31:Exchange requirements with IFC mapping	83
Table 32:Selected example weather data sources on EnergyPlus weather database	88
Table 33: Pre-design phase recommendations.....	92
Table 34: Conceptual design phase recommendations	93
Table 35: Design development phase recommendations	93
Table 36: Final design phase recommendations	94
Table 37: Construction phase recommendations	95
Table 38: operation and maintenance phase recommendations.....	95
Table 39: Case Study BIM Use	97
Table 40:Detailed Design Revit Results	125
Table 41 : First roof surface alternatives results	129
Table 42: Second roof surface alternatives results	130

NOMENCLATURE

AEC	Architecture, Engineering, Construction
BEM	Building Energy Model
BIM	Building Information Modeling
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated Photovoltaics
BPS	Building Performance Simulation
COMETH	COre for Modelling Energy and THERmal comfort
CSP	Concentrating Solar Power
DD	Design Development
DNI	Direct Normal Irradiation
DXF	Drawing Exchange Format
EUI	Energy Use Intensity
eLOD	Geometry Level of Development
gbXML	Green Building XML
GHI	Global Horizontal Irradiation
GUI	Graphical User Interface
IDM	Information Delivery Manual
IFC	Industry Foundation Class
iLOD	Information Level of Development
ISCC	Integrated Solar Combined Cycle Power Plant
IMELS	Italian Ministry of Environment
IPD	Integrated Project Delivery
LOD	Level of Development