

DISSERTATION

MODEL-BASED SYSTEMS ENGINEERING APPLICATION TO DATA MANAGEMENT
FOR INTEGRATED SUSTAINABLE HUMAN SETTLEMENT MODELING

Submitted by

Anicet Adjahossou

Department of Systems Engineering

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2024

Doctoral Committee:

Advisor: Neil Grigg

Thomas Bradley

Steven Conrad

Bryan Willson

Anders Fremstad

Copyright by Anicet Adjahossou 2024

All Rights Reserved

ABSTRACT

MODEL-BASED SYSTEMS ENGINEERING APPLICATION TO DATA MANAGEMENT FOR INTEGRATED SUSTAINABLE HUMAN SETTLEMENT MODELING

The challenges associated with the transition from current approaches to temporary humanitarian settlement to integrated, sustainable human settlements is largely due to a significant increase in the number of forcibly displaced people over the last few decades, the difficulties of sustainably providing the needed services, and the prolongation of emergencies. According to the United Nations High Commissioner for Refugees (UNHCR)'s Global Appeal 2023, more than 117.2 million people were forcibly displaced or stateless in 2023, representing a little over 1% of the world's population. The average lifespan of a humanitarian settlement is between 17 and 26 years (UNHCR), and factors such as urban growth and adverse environmental changes have exacerbated the scale of the difficulties. Despite these problematical contexts, short-term considerations continue to guide the planning and management of humanitarian settlements, to the detriment of more integrated, longer-term perspectives. These factors call for a paradigm shift in approach to ensure greater sustainability right from the planning phases. Recent studies often attribute the unsustainability of humanitarian settlements to poor design and inadequate provision of resources and basic services, including water, energy, housing, employment and economic opportunities, among others. They also highlight apparent bottlenecks that hinder access to meaningful and timely data and information that stakeholders need. More often than not, humanitarian operations rely on ad hoc methods, employing parallel, fragmented and disconnected data processing frameworks, resulting in the collection of a wide range of data without subsequent

analysis and prioritization to optimize potential interconnections. In addition, little effort was made to explore trade-offs that might improve sustainability. As a result, major shortcomings emerged along the way, leading to disruptions, budget overruns, messes and much more, against a backdrop of ever-decreasing funds for humanitarian aid. However, some attempts have been made to move towards more sustainable design approaches, but these have mainly focused on vague, sector-specific themes, ignoring systemic and integrative principles.

This research is a contribution to filling these gaps by developing more practical and effective solutions, based on an integrated systemic vision of a human settlement, defined and conceptualized as a complex system. To this end, this research proposes a model-driven methodology, supported by Model-Based Systems Engineering (MBSE) and a Systems Modeling Language (SysML), to develop an integrated human settlement system model, which has been functionally and operationally executed using Systems Engineering (SE) approach. This novel system model enables all essential sub-systems to operate within the single system, and focuses on efficient data processing. The ultimate aim is to provide a comprehensive solution to the interconnection and integration challenges encountered in the processing of operational data and information, to ensure an effective transition to sustainable human settlements. With regard to the interconnectedness between the different sectors of the sub-systems, this research proposes a Triple Nexus Framework (TNF) in an attempt to integrate water, energy and housing sector data derived from a sub-system within the single system by applying systems engineering methods.

Systems Engineering, based on an understanding of the synergies between water, energy and housing, characterizes the Triple Nexus Framework and identifies opportunities to improve decision-making steps and processes that integrate and enhance quality of data processing. To test and validate the performance of the system model, two scenarios are executed to illustrate how an

integrated data platform enables easy access to meaningful dataset as a starting point for modeling an integrated system of sustainable human settlement in humanitarian contexts. With regard to framework performance, the model is simulated using a megadata nexus, as specified by the system requirement. The optimization simulation yields 67% satisfactory results which is further confirmed from a set of surveyed practitioners. These results show that an integrated system can improve the sustainability of human settlements beyond a sufficiently acceptable threshold, and that capacity building in service delivery is beneficial and necessary. The emphasis on comprehensive dataset processing through systems integration can be a powerful tool for overcoming gaps and challenges in humanitarian operations. Structured interviews with question analysis are conducted to validate the proposed model and framework. The results demonstrate a consensus that the novel system model advances the state of the art in the current approach to human settlements design and management. An operational roadmap with substantial programmatic and technical activities required to implement the Triple Nexus Framework is recommended for adoption and scaling-up.

Finally, to assess the applicability and sustainability of the system, the proposed system model is further validated using a context-based case study, through a capacity assessment of an existing humanitarian settlement. The sustainability analysis uses cross-impact matrix multiplication applied to classification (MICMAC) methodology, and the results prove that the development of the settlement is unstable and therefore unsustainable, since there is no apparent difference between influential and dependent data. This research tackles an important global challenge, providing valuable insights towards sustainable solutions for displaced populations, aligning with the UN 2030 Agenda for Sustainable Development.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Almighty God for allowing me to carry out this research project and bring it to a successful conclusion.

In memory of my beloved parents, René Adjahossou and Ayekotan Ahoyo-Akpagbe. My most meaningful gratitude is reserved to you. It is with a feeling of immense accomplishment that I dedicate this doctorate to you. May you both rest in peace!

This work has benefited from the contributions of many people, both directly and indirectly. First of all, I would like to express my deep gratitude to my Faculty Advisor, Dr. Neil Grigg, for believing in me and persuading me from day one of your availability. Your stringent instructions and recommendations have been extremely valuable throughout my studies and research in the Systems Engineering program. Your understanding of my research subject in the humanitarian field, your support and guidance were very helpful in refining, contextualizing, and structuring my research methodology. I am particularly honored to have worked with such an Emeritus Professor as you are. My deepest thanks and appreciations go to Dr Thomas Bradley, who very early on had an understanding of my research objectives and immediately steered me towards the best methodology throughout the research and interview process. I am particularly indebted to you for your invaluable advice and instructions, which further enabled me to apply the MBSE methodology as required. I am proud to have worked with you.

To all the members of my Faculty Committee, Dr Steven Conrad, Dr. Bryan Willson and Dr. Anders Fremstad, I am indebted to you for your trust and guidance throughout my studies and during the research phase.

I am also grateful to the Colorado State University, the Department of Systems Engineering, for making this program a reality, thanks to its culture of academic excellence and research, particularly in the field of Systems Engineering.

In addition, I would like to thank the United Nations High Commissioner for Refugees and the Assistant High Commissioner for Operations, Mr. Raouf Mazou for his unwavering encouragement and support in the pursuit of this degree and my professional success. To Dr. Pierre Atchom, UNHCR Deputy Representative, for his advice and significant contributions to the research results, and who supported this research and its application in humanitarian contexts.

And above all, a big thank you to my family. Infinite gratitude to my four children, Yann, Anissa, Nohlan and Asher, for their patience, understanding and, most importantly, sacrifice. Thank you for doing your best to understand why Daddy has to do homework most of the time, including on official trips. I love you more than anything.

To my dear loving wife, Celine Raymonde-Dossi, infinite gratitude for having been present from the beginning to the end of my doctorate, for having unwaveringly supported me with sacrifices throughout this journey. Thank you for your unconditional support and love. Your presence in my life is a precious gift from God the Almighty, at every moment of my life. Gratitude for your unfailing selflessness and trust. I want you to know that your sacrifices have been at the forefront of my doctorate and professional career. Your prayer for me was what sustained me thus far. I love you forever.

DEDICATION

I declare that this dissertation completed, submitted, and presented to Colorado State University for the degree of Doctor of Philosophy is my own work. It contains no material previously published or written by another person or material which has been accepted for the award of any other degree or diploma of the University or another institute of higher learning.

All other related work of other authors is acknowledged, and a list of related references is provided and included in this dissertation.

Anicet Adjahossou

Summer 2024

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	v
DEDICATION.....	ii
LIST OF TABLES.....	xii
LIST OF FIGURES.....	xiii
CHAPTER ONE: INTRODUCTION.....	1
1.1. Overview.....	1
1.2. Humanitarian Settlement Overview.....	3
1.3. Access to Water, Energy and Housing in Humanitarian Settlements.....	9
1.4. Organizational Data Management.....	10
1.5. Research Approach.....	12
CHAPTER TWO: RESEARCH QUESTIONS AND TASKS.....	15
2.1. Research Question 1: State of Humanitarian Settlement and Operational Data Management.	15
2.1.1. Task 1.....	15
2.1.2. Task 2.....	15
2.2. Research Question 2: Conceptualization and Modeling of an Integrated Sustainable Human Settlement System and the Triple Nexus.....	16
2.2.1. Task 1.....	16
2.2.2. Task 2.....	17
2.3. Research Question 3: Context-based Case Study for System Sustainability Analysis.....	17
2.3.1. Task 1.....	17
2.3.2. Task 2.....	18
2.3.3. Task 3.....	18
CHAPTER THREE: INTEGRATED HUMAN SETTLEMENT SYSTEM AND OPERATIONAL DATA MANAGEMENT.....	19
3.1. Introduction.....	19
3.2. Research Question 1.....	20
3.3. Humanitarian Settlement Organization – A Literature Review.....	20
3.4. Influencing Factors in Current Operational Data Management.....	33

3.5. Application of Systems Engineering (SE)	35
3.6. Conclusion.....	41
CHAPTER FOUR: MODEL-BASED SYSTEMS ENGINEERING (MBSE) AND SYSTEMS MODELING LANGUAGE (SysML) APPLICATION TO THE CONCEPTUALIZATION OF A HUMAN SETTLEMENT SYSTEM AND A TRIPLE NEXUS MODEL	42
4.1. Research Question 2.....	42
4.2. Definition of the Concept of Sustainable Human Settlement	42
4.3. Integrated Human Settlement Concept Definition	46
4.4. Integrated Human Settlement System Architecture	47
4.5. Research Gaps	50
4.6. Conceptualisation of an Integrated Human Settlement System using the Model-Based Systems Engineering (MBSE) Approach.....	51
4.6.10. SysML Diagram Overview.....	61
4.6.11. Development of the Initial Integrated Human Settlement System	63
4.7. Chapter Summary.....	68
CHAPTER FIVE: INTEGRATED HUMAN SETTLEMENT SYSTEM MODELING	70
5.1. Introduction	70
5.2. Integrated Human Settlement System Model.....	71
5.2.1. Methods, Tools, and Process.	71
5.2.2. Logical Architecture of Human Settlement System	73
5.2.3. Stakeholders Participation	75
5.2.4. System Requirements	76
5.2.5. State Machine High-level Behavioral Diagram.....	79
5.2.6. System Data Processing Operations	81
5.3. Integrated Human Settlement System Capacity Analysis.....	90
5.4. Triple Nexus Framework (TNF)	91
5.4.1. Background to the Triple Nexus Framework	91
5.5. Triple Nexus Optimization Analysis.....	98
5.6. Triple Nexus Framework Modeling	101
5.6.1. Behavioral Modeling	101
5.6.2. Constraint Analysis.....	102
5.7. Structured Interview Results	104
5.7.1. Introduction	104

5.7.2. Organization and Interview Process	105
5.7.3. Interviews Results Analysis.....	113
5.7.4. Findings and Conclusions.....	119
5.7.5. Application of the Q-Statement Methodology	120
5.7.6. Conclusion of Q-Statement Application.....	129
5.7.5. Recommendations and Scaling up.....	130
5.7.6. Chapter Summary.....	132
CHAPTER SIX - CASE STUDY: SYSTEM SUSTAINABILITY ANALYSIS THROUGH CAPACITY ASSESSMENT AND MATRIX OF CROSSED IMPACT MULTIPLICATION APPLIED TO A CLASSIFICATION (MICMAC) ANALYSIS	135
6.1. Sustainability Perspective in Human Settlement System.....	135
6.2. Research Question 3 - To what extent does the system capacity affect the overall system sustainability over time?.....	136
6.2.1. System Sustainability Concept	136
6.2.2. System Capacity Concept.....	137
6.2.3. Study Area - Kalobeyei Integrated Settlement	137
6.2.4. Sustainability in Kalobeyei Settlement.....	139
6.2.5. Kalobeyei Settlement Programmatic Framework.....	140
6.2.6. Methodology and Tools.....	142
6.3. Chapter Summary.....	152
CHAPTER SEVEN: RESEARCH CONTRIBUTIONS AND CONCLUSIONS.....	154
7.1. Research Contributions	154
7.2. Research Conclusions	157
7.2.1. Dissertation Summary	157
7.2.2. Chapter Summaries.....	159
7.3. Future work	161
REFERENCES	164
APPENDIX A – SysML Block Definition Diagrams and Activity Diagrams	180
APPENDIX B – SysML Parametric Diagrams	185
APPENDIX C – SysML Parametric Diagrams and Block Definition Diagram.....	187
APPENDIX D – SysML Block Definition Diagram showing Triple Nexus Optimization	190
APPENDIX E - Triple Nexus Framework Modelling SysML Diagrams.....	196
APPENDIX F: Structured Interviews & and Results	198

APPENDIX G: Q-Statement Overview	206
LIST OF ABBREVIATIONS.....	209

LIST OF TABLES

Table 1: Minimum Standard for Camp Planning (Adapted from UNHCR).....	28
Table 2: Multi-dimensional interlinkages between water, energy, and housing.....	37
Table 3: Definition of a human settlement with data sharing, interconnectivity, and interdependency perspective.....	44
Table 4: Definition of a human settlement from economic growth and service delivery perspective (ex: water, housing, energy, economic, social.....)	45
Table 5: Definition of a human settlement from human resource perspective.....	45
Table 6: List of Six Sub-Systems of Integrated Human Settlement.....	48
Table 7: Level of subsystems integration (Adapted from [98]).....	49
Table 8: System and Triple Nexus Framework Interview Analysis [Adapted from 106, 107, 108].....	115
Table 9: Q-Sort for Participant P1.....	122
Table 10: Summary Q-Sorts by the 10 Participants (Respondents).....	123
Table 11: Correlation matrix between Q-Sorts.....	124
Table 12: Unrotated Factor Loadings.....	125
Table 13: Factor Q-Sort Values for Each tatement.....	126
Table 14: Distinctive Statements of Factor 1.....	127
Table 15: Distinctive Statements of Factor 2.....	128
Table 16: Distinctive Statements of Factor 3.....	129
Table 17: Distinctive Statements of Factor 4.....	129
Table 18: Kalobeyei Settlement Programmatic Framework (Adapted from [87]).....	141
Table 19: Alignment Between Kalobeyei Settlement Components (Adapted from [87]) and the Proposed Integrated Human Settlement Model.....	142
Table 20: Capacity Types and Requirements (Adapted from 87).....	145
Table 21: List of Capacity Types and Requirements (Adapted from 87).....	148

LIST OF FIGURES

Figure 1: Number of People Living in Urban and Rural Areas, World (1960 – 2021).....	5
Figure 2: Forcibly Displaced People Worldwide (2022-2022).....	5
Figure 3: Household Water Consumption in Kenyan Refugee Settlements.....	7
Figure 4: Household Houses Construction in Kenyan Refugee Settlements (Kakuma Camp and Kalobeyei Settlement, October 2023).....	7
Figure 5: Household Energy Consumption in Kenyan Refugee Settlements (Kakuma and Kalobeyei Settlements, October 2023)	8
Figure 6: UNHCR Data Types showing a Decentralized Processing of Water, Energy, and Housing data [Adapted from [19)].....	31
Figure 7: Schematic Representation of the Triple Nexus Processing.....	39
Figure 8: Schematic Representation of the Triple Nexus Framework Operations	40
Figure 9: Representation of the Integrated Human Settlement System.....	47
Figure 10: SE V-Diagram Representing Requirements Analysis and Allocation	53
Figure 11: Flowchart showing the Principal Stages in a System Life cycle. Adapted from [93].	53
Figure 12: Spiral Model (Adapted from [95])	54
Figure 13: Simplified System Engineering Technical Process (Adapted from [96])	55
Figure 14: Simplified Visualization of the Layered MBSE Iteration (Adapted from [99])	56
Figure 15: OOSEM Foundation (Adapted from [92])	58
Figure 16: OOSEM Activities for the System Development Process. (Adapted from [92]).....	59
Figure 17: Relationship of SysML to UML (Adapted from [96])	60
Figure 18: SysML Diagram Taxonomy and SysML-UML Relationship (Adapted from [96]) ...	62
Figure 19: Simplified SysML Integrated Human Settlement System Structure.....	65
Figure 20: Simplified SysML Triple Nexus System Structure.....	66
Figure 21: SysML Integrated Data Platform Diagram for a Settlement System	68
Figure 22: : System Model Development Conceptual Model	72
Figure 23: SysML BDD Diagram showing a Logical Architecture of the Integrated Human Settlement System.....	74
Figure 24: SysML BDD Diagram showing System’s Stakeholders Composition	76
Figure 25: SysML of the Proposed System Requirements Diagram	78
Figure 26: SysML High-level State Machine Diagram	80
Figure 27: SysML Integrated Settlement System Diagram showing the Data Integration Processing	83
Figure 28: SysML Integrated Settlement System Diagram showing the Information Processing	84
Figure 29: SysML Integrated Settlement System Diagram showing the Integrated Data Platform	85
Figure 30: SysML Integrated Human Settlement System Diagram showing the Integrated Data Platform.....	86
Figure 31: SysML State Machine (STM) Diagram showing Model Operations.....	87
Figure 32: SysML Block Definition Diagram of System Capacity Analysis Representation	88

Figure 33: SysML Block Definition Diagram of Capacity Analysis showing the System Requirements	89
Figure 34: SysML Block Definition Diagram showing the Nexus Framework Structure	92
Figure 35: SysML Block Definition Diagram showing the Nexus Integrated Data Platform.....	94
Figure 36: Simplified SysML Block Definition Diagram showing the Nexus Integrated Data Platform.....	95
Figure 37: SysML Block Definition Diagram illustrating the Nexus Information Platform.....	96
Figure 38: SysML State Machine High Level Illustration of the Triple Nexus Operations.....	97
Figure 39: SysML Block Definition Diagram showing the Triple Nexus Data Processing.....	100
Figure 40: SysML Activity Diagram for Nexus Framework Behavior Model (Adapted from [104]).....	103
Figure 41: Activity Diagram for Nexus Decision Support Process (Adapted from [104])	104
Figure 42: KISED P eight complementary components (or subsystems).....	138
Figure 43: Sustainability Capacity Assessment Methodology Process	143
Figure 44: Representation of the Six Categories Interconnected Subsystems Focused on Data and Service (Adapted from [87]).....	144
Figure 45: Sustainability Variables Diagram by Influence and Dependence	149
Figure 46: (idem 33): SysML Block Definition Diagram showing the System Requirements ..	180
Figure 47: Activity Diagram showing Data Processing from the Urban Planning Sub-System	181
Figure 48: Activity Diagram showing Data Processing from the Institutional Sub-system.....	182
Figure 49: SysML Activity Diagram showing Data Processing from the Population Subsystem	183
Figure 50: Activity Diagram showing Data Processing from the Social Services Subsystem...	184
Figure 51: SysML Parametric Diagram showing the System Requirement Constraints.....	185
Figure 52: SysML Real Time Parametric Diagram showing System RT Constraints	186
Figure 53: SysML Time Serie Chart showing the System Capacity Analysis Result	187
Figure 54: SysML Block Definition Diagram showing System Capacity in Real-Time (RT) Data Processing	188
Figure 55: SysML Time Serie Chart showing RT Data Processing	189
Figure 56: SysML Block Definition Diagram showing the Triple Nexus Data Processing.....	190
Figure 57: SysML Sequence Diagram showing Data Integration Process	191
Figure 58: SysML Activity Diagram showing Properties Iteration based on the Proposed Nexus Data Processing.....	192
Figure 59: SysML Activity Diagram showing Properties Iteration based on the Current Data Processing	193
Figure 60: SysML Parametric Diagram of Triple Nexus Capacity Analysis	194
Figure 61: Parametric Diagram of Triple Nexus Optimization Process	194
Figure 62: Nexus Optimization Simulation Configuration Results	195
Figure 63: (idem 40) SysML Activity Diagram for Nexus Framework Behavior Model (Adapted from.....	196
Figure 64: (idem 41) Activity Diagram for Nexus Decision Support Process (Adapted from [104]).....	197

CHAPTER ONE: INTRODUCTION

1.1. Overview

The overriding challenges involved in reorientating humanitarian settlement planning towards more integrated, sustainable human settlement are largely due to the substantial increase in the number of forcibly displaced people over the last few decades, and the protracted nature of emergencies. The approaches adopted over the years has been based on the assumption that emergencies are ‘temporary’ and that solutions to displacement problems would soon be found. In addition, factors such as urban growth and climate change have exacerbated the scale of the problems. Consequently, current approaches to the planning and development of humanitarian settlement that fail to integrate sustainable parameters into the design phases are no longer viable in the long term [2]. In most existing humanitarian settlements, poorly engineered plans have strained limited resources such as water and energy, housing among others, in addition to inefficient land use and ad hoc development models that have exacerbated the difficulties [3]. This has led to a deterioration of settlements over the last few decades, and continues to pose challenges for humanitarian actors as to how best to design, plan and sustain humanitarian settlements over time. Admittedly, some initiatives have attempted to address these challenges, such as the Kalobeyei integrated refugee settlement in Kenya [3]. However, the approach by which it has been conceived and developed has not reflected a systemic view, the interconnection between the various elements is still fragmented, disconnected [4], and the transition has only been thematic, displaying piecemeal sectoral planning methods. As far as data management is concerned, storage in disconnected databases does not facilitate multi-sector analysis for forward-looking prioritization, and it is difficult to establish interconnections between sectors.

The motivation of this research is to solve these difficulties by applying a Model-Based Systems Engineering (MBSE) approach to develop an integrated and sustainable human settlement system. Leveraging sustainability attributes, a new Triple Nexus Framework for water, energy and housing is developed to integrate and streamline data from all three sectors onto a single integrated platform. The proposed model and the Triple Nexus Framework have been tested and validated by professionals and experts with real expertise and experience in humanitarian operations, urban planning and data management through structured interviews. Understanding how a human settlement and its built environment interact is fundamental to ensure a sustainable development [5]. In light of this, Douglas I. [6] pointed out that human settlements form an environment that provides residents with amenities and quality of life but they are also a source of pressure on the natural environment where human activities draw on resources and materials are transformed into products for consumption. Thus, a human settlement can be viewed as a socio-technical complex, and it would be obvious from a principle of superimposed structures that the concept of a sustainable human settlement has similar complexities to those of urban cities. However, it should be noted that, compared with these analogous systems, a humanitarian settlement is characterized by the centrality of humanitarian activities with a wide range of stakeholders.

In this research, the human settlement is considered as a complex social system, made up of six subsystems that are all interdependent and interrelated. To function as a system, all subsystems are integrated through a single platform that consolidates and processes data sets in a meaningful way. To ensure the sustainability of such a system, it is required to plan, design, develop and manage it as an integrated system that enables all subsystems to be interconnected and function as a whole. To achieve these goals, this research argues that the system's capacity to capture, integrate and ensure the flow of data between sub-systems could help to reach a desired level of

sustainability. Over the years, the humanitarian operations have been implemented according to a standard cycle [7] which is reflected in results-based management (RBM) process. The five key stages of the cycle [7] are (1) stakeholder analysis; (2) needs assessment and problems analysis; (3) prioritization and planning; (4) projects or activities implementation; and (5) monitoring, evaluation, and reporting. In practice, different methods support the implementation of RBM, including participatory planning, analysis and definition of stakeholders and their needs, bottom-up approaches, and a people-centered planning framework. This research emphasizes on refinement and improvement of step 2, which ensures that data generated from needs assessment is consistently integrated, processed, and made available to stakeholders in real-time. By innovating in this earliest planning stage of RBM, this research outcomes have the potential to significantly affect the design and management of humanitarian settlements towards more sustainable practices, aligning with current global priorities.

1.2. Humanitarian Settlement Overview

In February 2023, the United Nations estimated that the total number of displaced populations would reach over 117 million, up from 103 million in 2022 while less than 1% of them can return home, a figure that has more than doubled over the past two decades [2]. According to UNHCR, the average lifespan of a refugee settlement is between 17 and 26 years [8]. The World Bank reported in 2023 that globally over 10 million displaced people are settled in developing countries, many of them are self-settling within host communities, sharing overcrowded accommodations in substandard or unfinished settlements. In addition, the UN estimates that around 70% of settlements are informal, lacking security of tenure, access to basic services, limited resources, inadequate planning, and often located in geographically and environmentally hazardous areas. Although humanitarian settlements are often seen as isolated systems, they depend on complex governing

bodies that function like a city [9]. Most humanitarian settlements are located in countries confronted with rapid urbanization and excessive pressure on natural resources, with enormous constraints on quality of life [6]. According to the World Bank Group [10], most human settlements hosting forcibly displaced people lack reliable infrastructure and urban bases [11]. What's more, over 30% of these settlements, located in rural or peripheral areas, are experiencing massive urbanization [10], and the ongoing transition will undoubtedly affect their sustainable development. This change in population dynamics and the accelerated urbanization in rural refugee-hosting areas will exert considerable pressure on human settlements and hamper their prosperity. Consequently, a new approach to the planning and development of human settlement in the coming years will need to anticipate future changes and gradually adapt to urban principles inspired by systems approaches. As indicated by the World Bank [12] and shown in Figure 1, in 2007 the world's urban population (3.36 billion) overtook the rural population (3.35 billion), marking the beginning of a new "urban millennium". Based on this scenario¹, the UN estimates that by 2050, 70% of the world's population will be living in cities, while humanitarian settlements are also facing significant population growth. According to UNHCR's 2022 global trends, as of December 2022, 108.4 million people worldwide were forcibly displaced, representing 15% increase compared to the end of 2021. As shown in Figure 2, there is a continued increase in the number of displaced people in humanitarian settlements over the last few decades, with an average refugee population growth of 12% every year, while the internally displaced population growth is about 11% every year. This would mean that today's rural centers in developing countries, where

¹ World Bank (2020). The World's Urban Population Growth. Available at: http://www.theatlant.com/charts/rkvEwGY_x. [Accessed on 17 August 2020].

most refugee settlements are located, will gradually have to transition into urban or peri-urban centers.

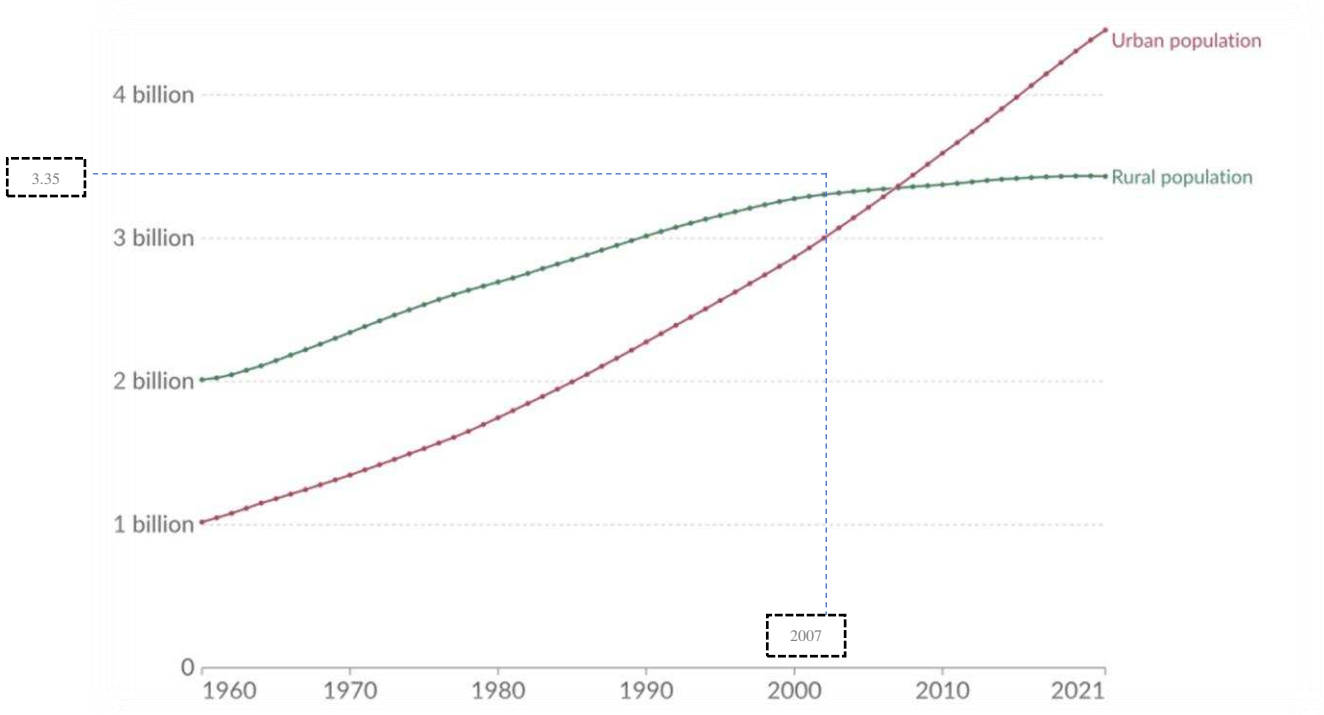


Figure 1: Number of People Living in Urban and Rural Areas, World (1960 – 2021)

Data source: World Bank Based on Data from the UN Population Division

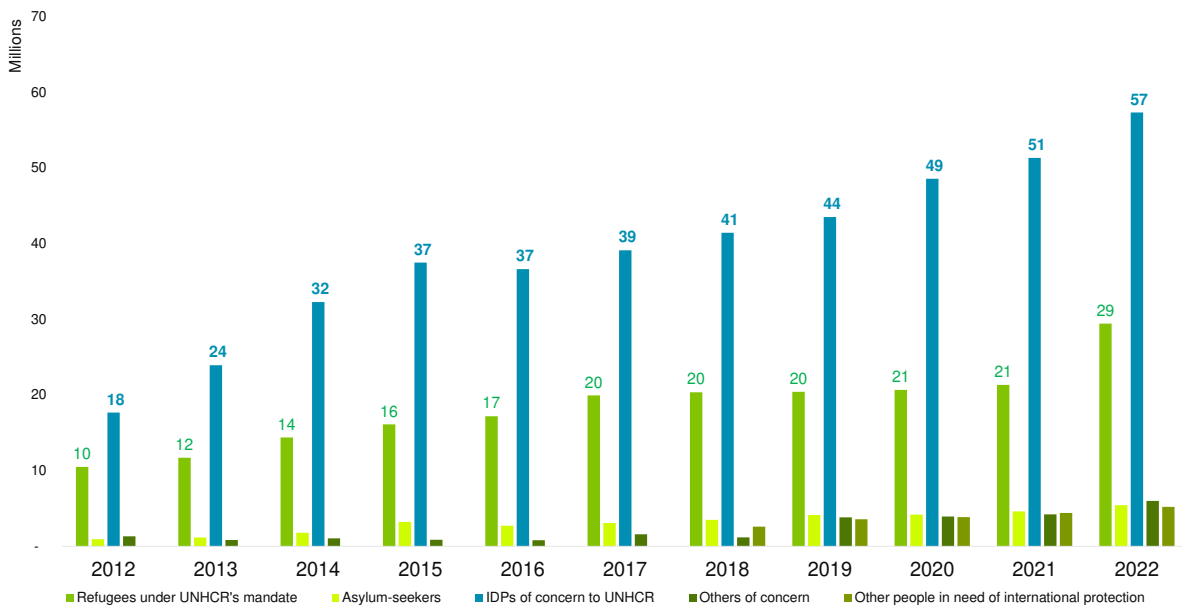


Figure 2: Forcibly Displaced People Worldwide Source: UNHCR Global Trends 2022

For decades, humanitarian settlements have suffered the consequences of inadequate design, resulting in unsustainable development [13]. Although they are drivers of socio-economic development, quality of life has recently deteriorated. This steady decline is mainly attributed to the sharp increase in displaced populations and rapid urbanization in developing countries, which now host around 30% of humanitarian settlements. Many humanitarian organizations have often deplored the fact that most settlements are faced with "splintered urban planning" which calls into question their sustainability due to a lack of integrated multi-sectoral planning and data availability. Data management in settlement is also highly decentralized. There is a form of "ad hocism" in which sector-specific data is collected, then forgotten or stored in an inaccessible way, resulting in wasted time and duplication of efforts when planning for subsequent years [12].

In October 2023, as part of fieldwork in Africa, a household survey was carried out in two refugee camps in Kenya to understand performance against required standards in the services provided to the population. The results revealed significant gaps in the provision of basic services to refugee populations. For example, although refugees receive on average 17 liters of water per person per day (compared with 20 liters per person per day according to UNHCR standards), 75% of households reported they needed more water for a variety of other needs, including economic activities and housing construction. In addition, half of all households need more energy, and only 83% of them are able to buy the energy they need for their livelihoods and economic activities, as shown in Figure 4.

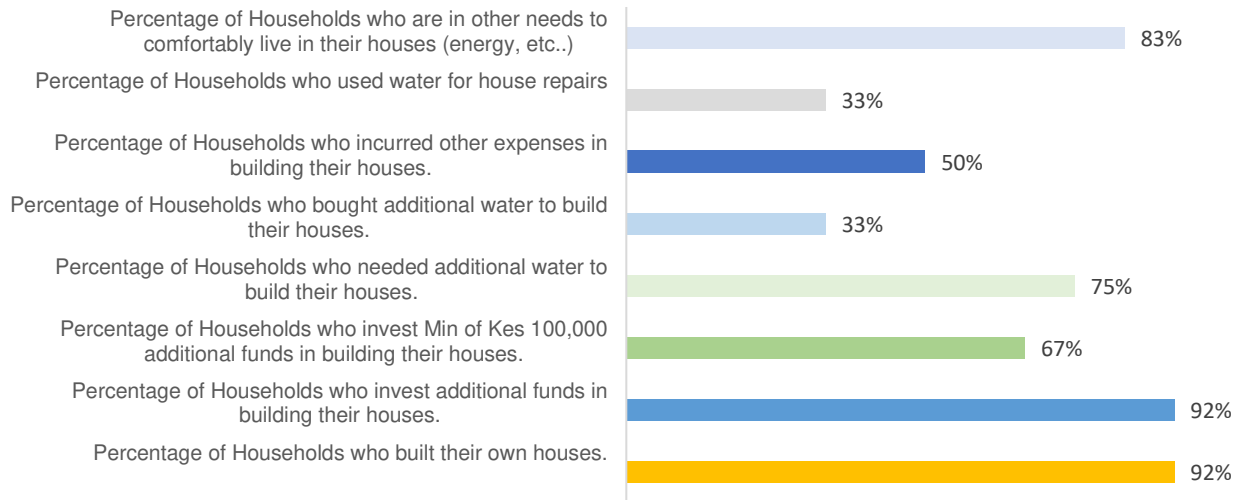


Figure 3: Household Water Consumption in Kenyan Refugee Settlements
(Kakuma Camp and Kalobeyei Settlement, October 2023)

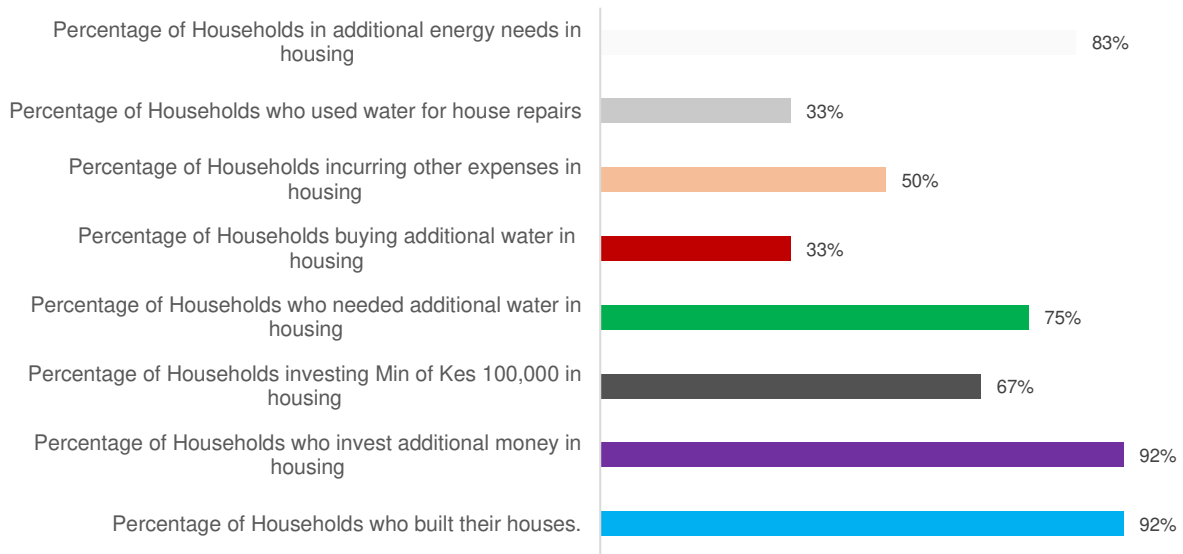


Figure 4: Household Housing Construction in Kenyan Refugee Settlements
(Kakuma Camp and Kalobeyei Settlement, October 2023)

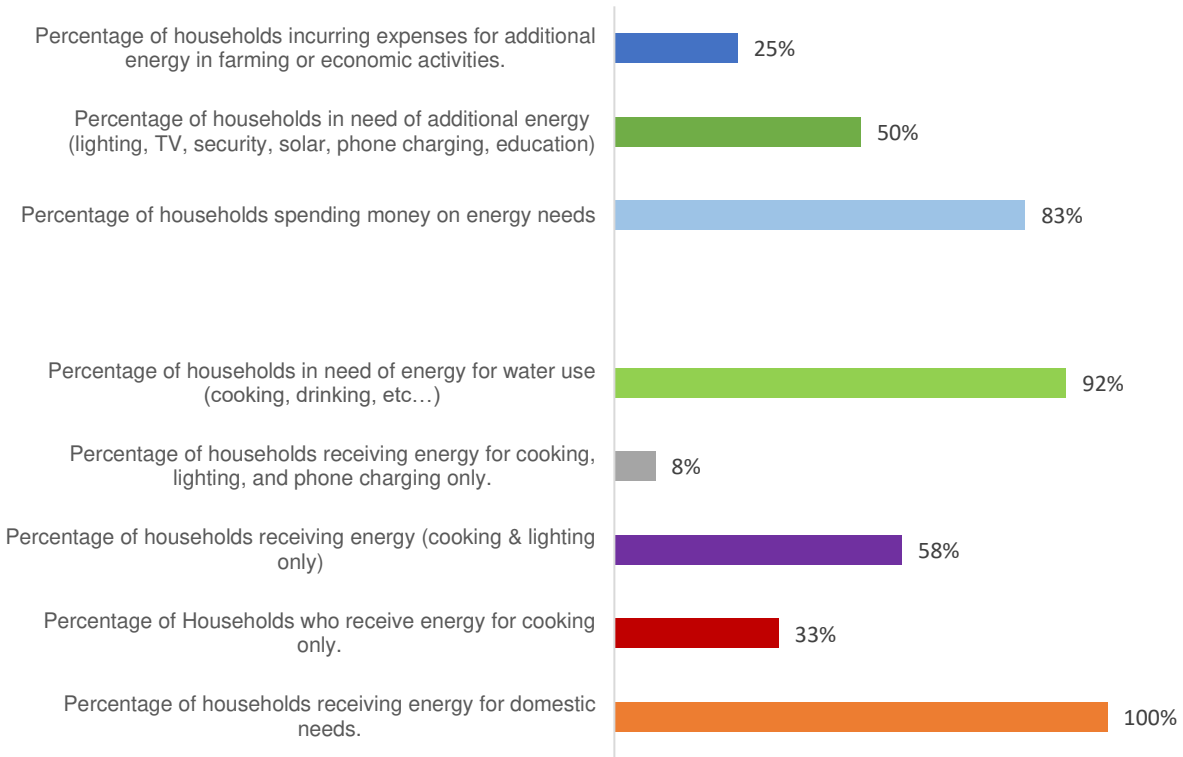


Figure 5: Household Energy Consumption in Kenyan Refugee Settlements
(Kakuma and Kalobeyi Settlements, October 2023)

In addition, analysis of the results also revealed significant discrepancies between planning data (according to which 17 to 20 liters of water per person are sufficient for typical domestic uses such as drinking, washing and cooking) and actual implementations (in which the construction of houses constitutes an additional water requirement for households). This example shows that, as operational data (on water requirements) is collected in isolation, the population needs are met in a scattered manner. As a result, standards are often not met and people are forced to find alternatives to compensate for the shortfalls or make substitutions. These results also show that the challenges of moving human settlements towards a more sustainable direction are enormous, and require more systematic and holistic actions and solutions.

1.3. Access to Water, Energy and Housing in Humanitarian Settlements

Access to water in humanitarian settlements is vital for displaced people. However, according to UNHCR statistics, more than half of the world's refugees do not have access to the minimum quantity required by international standards. UNHCR estimates that more than half of the world's refugee camps do not have enough water to meet the standard of 20 liter per person per day [14], and according to the 2023 Global Water Security Assessment report [14], 78% of the world's population currently lives in countries where access to drinking water is not guaranteed. Furthermore, the assessment report reveals that the world's population is expected to reach 10 billion by 2050, of which approximately 4 billion are expected to live in water-stressed basins [15].

On the other hand, growth in global energy demand is relatively modest due to the widespread deployment of energy-efficient technologies and the global economy's transition to service-based economies. However, energy demand is expected to increase by 37% by 2040 [16]. Most refugees rarely have access to suitable energy resources. It is estimated that 80% of the 8.7 million displaced people use traditional biomass for cooking, have no access to electricity and rely mainly on nearby forests for firewood. As a result, hectares of forest are cleared and burned every year in areas close to refugee settlements [17]. Limited access to energy resources in settlements has a negative impact on the sustainability and security of displaced populations. While equitable and secure access to clean and affordable energy is closely linked to the satisfaction of needs related to water, housing, and education, access to energy remains a major challenge in most humanitarian settlements.

Similarly, access to sustainable, safe and affordable housing is a continuing challenge for displaced people. According to UNHCR, around 30% of refugees are hosted in self-constructed settlements [18] and are forced to live in substandard housing. Refugees living in urban areas also face similar challenges, since most of them live in informal, unplanned settlements. Less than 20%

of them have access to housing that complies with norms and standards, and is provided with adequate water and energy.

Indeed, water, energy, and housing are intrinsically interrelated, and the provision of one generally depletes the resources of the other two and vice versa, due to the environment that produces them and the institutional arrangements that are in place. In most humanitarian settlements, important decisions across the three sectors are typically not coordinated. For example, sustainable energy policies are typically based on the idealistic assumption of abundant water for potential energy solutions such as evaporative coolers. Building high-quality housing requires high water-intensive materials. Collecting and filtering clean water requires energy resources that must be built and managed. This dynamic, urbanized, and interconnected context must innovate to move away from fragmented governance. The interconnections between energy, water, and housing influence the extent to which system sustainability can be achieved with respect to these three resources, among others.

1.4. Organizational Data Management

In terms of data management, the typical *modus operandi* is a form of “ad hocism” data processing. UNHCR continues to implement parallel and fragmented approaches to operational data collection and processing. For example, UNHCR collects a wide range of multi-sectoral dataset, but their analysis does not provide tangible linkages that could be used to streamline and improve expected performances. Efforts to share the benefits of data integration are relatively limited. As highlighted in the UNHCR’s Evaluation Report on Data Management [19], as part of efforts to strengthen data integration and accessibility, in 2018 UNHCR rolled out a Population Registration and Identity Management Ecosystem (PRIMES), which is a new approach to aggregating data from registration and identity management. PRIMES is also capable of

integrating and sharing data with other internal and external applications. With regard to operational data management, some efforts are being made through the Raw Internal Data Library (RIDL), which aims to gather and store large amounts of operational data from needs assessments, and protection monitoring that UNHCR collects directly or indirectly through its partners. However, this the collection of these vast datasets remains too sectoral without any integration efforts, and is not carried out in a structured manner, but simply as an internal data warehouse that does not sufficiently and efficiently offer a possibility of their integration for multipurpose use.

In practice, efficiency in water supply to improve consumption and reduce shortages is examined from a water point of view, and energy production for domestic and economic activities is estimated from an energy angle. Energy requirements are often estimated only from the perspective of energy needs, and this approach has been sufficiently investigated by Al-Saidi [20]. At the same time, housing efficiency is perceived primarily in terms of the construction of housing. As a result, significant gaps have emerged over time, as highlighted in the UNHCR evaluation report. For example, the current approach to energy supply planning has had unintended consequences that affect the well-being of refugees in Kakuma camp and Kalobetyei settlement [21]. In these settlements located in an arid region of Kenya prone to frequent and prolonged droughts, various options for addressing water scarcity require considerable energy to operate the solar system, which affects energy production and vice versa. Similarly, the construction of sustainable houses requires a large amount of water, which affects the water supply system often designed for domestic water use. This situation, which results from an “isolationist” approach in the design and implementation of these systems, still persists today in the vast majority of humanitarian settlements.

The fundamental objective of this research is to address these overriding challenges in organizational data management by developing a practically generalizable model of integrated sustainable human settlement in which operational data is streamlined and processed through a modeled framework to improve current methods of data management. In this perspective, the research proposes a Triple-Nexus Framework (TNF) of Water-Energy-Housing that is conceptualized and modeled using Systems Engineering (SE) methods and tools. The Triple Nexus, which emphasizes Model-Based Systems Engineering (MBSE) to streamline data processing in the water, energy, and housing sectors, represents a significant advance in the field of optimizing humanitarian operations. Therefore, the proposed Water-Energy-Housing Triple Nexus Framework introduces a new perspective on the integration of essential resources in humanitarian settlements, addressing the urgent need for sustainability in these areas.

1.5. Research Approach

Based on the above reflections regarding the state of humanitarian settlements and the challenges of operational data management to achieve sustainability goals, I identified the opportunity for Systems Engineering (SE) and model-based applications to advance knowledge in humanitarian settlement planning and management. In these efforts, this research critically (1) examines existing practices and definitions of a humanitarian settlement concept, as a sustainable solution to the challenges faced by humanitarian practitioners and urban planners. Then, (2) develops a novel modeling methodology based on Model-Based Systems Engineering (MBSE), a methodology that is normally used in software engineering systems development, and a Systems Modeling Language (SysML), to design and test an integrated sustainable human settlement system and a Triple Nexus Framework based on the defined concept emphasizing the data perspective in a systematic view of the settlement system. The Triple Nexus is derived from one

of the subsystems of the system with the aim of highlighting the need and benefit of having an integrated model and meaningful real-time data processing. (3) Conducts an initial test and validation of the developed integrated system model and framework with the interviewed practitioners. (4) Assesses the sustainability of the system through a context-based case study focused on service delivery and capacity analysis using the Cross Impact Matrix Multiplication Applied to Classification (MICMAC) methodology.

The literature presents a variety of definitions and approaches to a human settlement that offer many perspectives, including those of people, services and data. While the approach presented in this work allows for considering the human settlement system from all possible angles, this research focused on the data management and capacity perspectives to develop and highlight a holistically integrated form.

To capitalize on these benefits, a literature review was conducted to deepen the understanding of human settlements and urban fundamentals, and to define the concept of integrated human settlement in the context of this research, after which a model-based methodology based on the Model-Based Systems Engineering (MBSE) approach and the Systems Engineering Modeling Language (SysML), was developed and used to model a typical integrated sustainable human settlement system. The aim was to illustrate the behavior of the system and demonstrate how an integrated data platform can serve as a framework that integrates the data that stakeholders need. The design of the model drew on UNHCR's master planning framework [8] and its multi-stakeholder engagement for human settlements [11], as well as an extensive literature review, to define the system and its subsystems or key areas that are most critical for the context. The system model focused on system integration and data processing that enable subsystems to function together on an integrated platform. Initial validation of the system model was presented through

the illustration of two scenarios that tested the system's capacity to process meaningful data in real time.

With the aim of advancing the knowledge on the integrated data management approach, this work develops a scaled Triple Nexus Framework by using the advantages offered by SE that would make data collection, management and processing more proactive, adaptive and efficient. The Triple Nexus Framework that integrates data from the water, energy and housing sectors is proposed to assess the capacity of the settlement system to efficiently handle multi-sector data and to test its performance in real-time. In particular, to determine whether the flow of a myriad of data sets across the system and subsystems can be streamlined, systematized, secured and accessible in real time through a single platform. To test the sustainability performance, the settlement system was evaluated through a case study to determine the capacity to achieve a certain sustainability threshold by applying a capability interdependence assessment method and the MICMAC (Cross Impact Matrix Multiplication Applied to Classification) methodology. The application of the MICMAC method allows to evaluate the interdependencies that exist between categories of subsystems to provide specific services at the system level and to test their formulations, either probabilistically or deterministically. Finally, the case study explores the operability of the system, its limitations and potential future improvements.

CHAPTER TWO: RESEARCH QUESTIONS AND TASKS

Chapter 2 presents the research questions and associated tasks to be carried out in the course of this research.

2.1. Research Question 1: State of Humanitarian Settlement and Operational Data Management.

What are the most significant shortcomings in current humanitarian settlement planning and operational data management that Mode-Based Systems Engineering (MBSE) may be able to address?

2.1.1. Task 1

With the aim of achieving sustainability in planning and management of humanitarian settlement over time, and based on the application of Systems Engineering, identify overriding shortcoming and knowledge gaps, as well as opportunities for SE and MBSE methodologies to define, conceptualize an advanced approach to a sustainable and integrated human settlement system.

- Result: Identification of major shortcoming and knowledge gaps, and definition of sustainable and integrated human settlement system.
- Method: Literature review, field observations, and SMEs consultations.

2.1.2. Task 2

Examination of the current state of practices and methods in humanitarian operations, particularly within the United Nations. This involves investigating how Model-Based Systems Engineering (MBSE) and Systems Modeling Language (SysML) can be applied to research, and what their advantages are in terms of organizational and operational data implications for greater sustainability over time.

- Result: Development of novel approaches to operational data processing.
- Method: A review of academic research, and using existing UNHCR data management frameworks.

2.1.3. Task 3

In line with SE applications, define the concept of an integrated human settlement system and the Triple Nexus Framework that advances knowledge in the planning and management of organizational and operational data.

- Results: Definition of the concept of Integrated Human Settlement System and the Triple Nexus Framework.
- Method: Cross-impact analysis, perspectives of data managers and SMEs.

2.2. Research Question 2: Conceptualization and Modeling of an Integrated Sustainable Human Settlement System and the Triple Nexus Framework.

Can Model-Based Systems Engineering (MBSE) methodology and Systems Modeling Language (SysML) effectively conceptualize and model an Integrated Sustainable Human Settlement System and the Triple Nexus Framework to address critical and current challenges?

2.2.1. Task 1

Based of the Systems Engineering (SE) methodology, conceptualize a typical Integrated Human Settlement System and a Triple Nexus Framework that enables a systematic and integrated view of the system. These models will be further developed in Task 2.

- Result: Conceptualization of the Integrated Human Settlement System and the Triple Nexus Framework.
- Method: Systems Engineering applications, UNHCR solutions guidelines, systems modeling tools.

2.2.2. Task 2

Application of Model-Based Systems Engineering (MBSE) methodology and Systems Modeling Language (SysML) to develop an Integrated Human Settlement Model and a Triple Nexus Framework focusing on operational data management and system capacity perspectives.

- Result: Modeling of an Integrated Human Settlement System and a Triple Nexus Framework that illustrate how an integrated data platform streamlines data and facilitates access to stakeholders.
- Method: MBSE and SysML using No Magic Cameo System Modeler software

2.2.3. Task 3

Define two scenarios to execute the system's performance and capacity to process a large amount of meaningful data in real time, and validate the proposed system models.

- Result: Simulation, testing and validation of integrated human settlement system and triple nexus for performance measurement.
- Method: MBSE and SysML using No Magic Cameo system modeler software, structured interview, Q-statements analysis, roadmapping.

2.3. Research Question 3: Context-based Case Study for System Sustainability Analysis.

To what extent does system capacity affect the sustainability of a human settlement system over time?

2.3.1. Task 1

Perform a system capacity interdependence analysis using the Matrix of Crossed Impact Multiplication Applied to Classification (MICMAC) methodology to assess the interdependencies that exist between sub-system categories to deliver services at the system level.

- Result: System Capacity Assessment Matrix.
- Method: Modeling capacity interdependency assessment, cross-impact analysis, MICMAC, UVC Framework application.

2.3.2. Task 2

Conduct a Double-Causality analysis (Cross-impact analysis) to map how the capacities of the six subsystems influence and depend on each other within the overall settlement system.

- Result: System double-causality analysis matrix or Cross-Impact matrix.
- Method: Modified version of UVC framework, expert's judgement.

2.3.3. Task 3

Perform a sustainability analysis to evaluate system's capacity and adaptability.

- Result: Settlement system capacity and performance measurement.
- Method: Cross-impact analysis, MICMAC, combination of Excel.

CHAPTER THREE: INTEGRATED HUMAN SETTLEMENT SYSTEM AND OPERATIONAL DATA MANAGEMENT

3.1. Introduction

Over the years, UNHCR has adopted temporary approaches to settlement planning and management, assuming that the situation of displaced people is temporary. However, as previously noted, less than 1% of displaced people are able to return home while the average lifespan of a refugee settlement is between 17 and 26 years [8]. Furthermore, this temporary settlement approach, compounded by poorly planned conditions, has placed considerable pressure on scarce natural resources. Low integration in settlement planning processes has also acted as a catalyst for inefficient data processing and management due to ad hoc development models, which has exacerbated unsustainable conditions and service delivery to encourage integration between settlement components and elements. Building on UNHCR's strategy (active for decades), the development of humanitarian settlements comprises three main phases - installation, maintenance, upkeep and closure - and the process often unfolds in six stages [22], each stage requiring the production, analysis and processing of a considerable amount of data. Throughout the lifecycle, data flow is essential for effective planning and management. Unfortunately, it has been observed that in addition to a lack of systemic thinking, there are inconsistencies in the processing of operational data. An evaluation commissioned by UNHCR in 2019 found that the consistency and quality of data within UNHCR varies considerably outside of structured systems due to several factors [19]. This evaluation found that UNHCR operations regularly collect data from needs assessments or from monitoring activities, which is supposed to be analyzed and used, either in

the programming cycle or for decision-making. However, these data are then archived and not used for any other purpose. As needs assessment data do not have a global storage platform, UNHCR does not have the means to realistically use them for further analysis. As a result, UNHCR has rich datasets from various assessments or monitoring but does not leverage them for further analysis, and standard processes for data collection, storage and sharing are inefficient and ineffective, as noted in the report. Given such challenges and inconsistencies, this Chapter aims to answer the first research question, which is restated below.

3.2. Research Question 1 – *What are the most significant shortcomings in current humanitarian settlement planning and operational data management that Mode-Based Systems Engineering (MBSE) may be able to address?*

To answer this question, Chapter 3 presents a review of the literature and UNHCR practices, and identifies the challenges and shortcomings the Agency faces and those that could be addressed by the application of model-based methodologies. It examines how a typical integrated human settlement system is defined, identifying the main subsystems and attributes that characterize it as a system. In particular, I describe the current approaches implemented by UNHCR and highlight the main challenges that require a change in methods, including corporate efforts to automate the management and sharing of operational data. The main objective is to understand the process of humanitarian settlement development and the importance of data, to present the state of the art in the field and to identify possible gaps. To do this, I have formulated a definition of an integrated human settlement in the context of humanitarian operations.

3.3. Humanitarian Settlement Organization – A Literature Review

The emergence of humanitarian settlements has been associated with forced displacement for decades. The objective sought has often been the creation of temporary conditions to

accommodate displaced populations in search of international protection. The literature review reveals that these temporary accommodations were initially spread in some thirty countries around the world with basic infrastructure and very limited resources. Some have existed for over 50 years, as evidenced by Palestinian camps established in the late 1940s. The Anthropologist Agier [17] estimated that 15 million people worldwide were living in humanitarian camps in 2014. In his study, Agier M. critically underlines that the "camp form" refers to three main characteristics: exceptionality, extraterritoriality, and exclusion, as they are mostly densely populated, not originally designed as a city integrated into the host territory. To prevent perpetuating the presence of displaced populations in the host countries, humanitarian settlements are often developed and maintained in a temporary status, even when they have existed for several years. This is the case of Zaatari settlement in a desert area, established in 2011 in Jordan to accommodate Syrian refugees, and which, by its size, was the fifth largest city in Jordan. Although, according to the UNHCR's emergency handbook [22], the selection of settlement sites is one of the critical factors, in most cases they fail to meet minimum standards. As a result, this has led to pendulum movements, loss of resources and negative impacts. More importantly, the creation of humanitarian settlements requires significant investment in infrastructure and social services, while maintenance costs are considerable. One of the most striking examples is the Dadaab refugee camp in Kenya, the country's tenth largest city in terms of population, with 233,828 refugees [23] as of 31 January 2023. Other camps with sub-standard figures and higher population densities, such as the Kakuma refugee camp in Kenya, for instance, in 2020, had a density of more than 10,000 people per square kilometer [24], and the Zaatari camp in Jordan, a density of 24,212 refugees per square kilometer [25]. Regardless of the location and status of these camps, the common denominator is to provide a living space that complies with humanitarian principles and

local regulations. For its part, by emphasizing the links between needs and resources, the United Nations High Commissioner for Refugees defines a refugee camp [26] as a structured landscape of a territory that takes into account the spatial distribution of functions while maintaining a balance between the needs of the population and the availability and distribution of resources. Therefore, a humanitarian settlement responds to the community's needs and the provision of socio-economic services that they require. From this definition, it can be understood that the planning and development of a refugee settlement must consider local dynamics and the needs of refugees. In the same spirit, the United Nations Human Settlements Programme [27] considers that a human settlement is an improvement in human well-being and that it must facilitate a rapid and continuous improvement in the quality of life of all, starting with the satisfaction of basic needs. On the other hand, the Organization for Economic Cooperation and Development (OECD)² defines a human settlement as an integrating landscape that includes physical elements and community services such as housing, education, health, culture, well-being, and nutrition, among others.

The literature review reveals that a humanitarian settlement is first and foremost a human settlement whose primary function is to ensure the well-being of displaced populations. Throughout this work, I refer to the humanitarian settlement as a socio-complex system, for which the application of systems engineering methods will allow exploring the dynamics associated with different elements of the system.

To deepen the analysis, this Chapter explores the concept of the humanitarian settlement, its characteristics and attributes. The United Nations High Commissioner for Refugee (UNHCR) defines a humanitarian settlement [26] as *“a structured landscape of a territory that takes into*

² Glossary of statistical terms - Organization for Economic Co-operation and Development - OECD, 2007.

consideration spatial allocation of functions while maintaining equilibrium between population needs, availability, and allocation of resources, economic dynamics, amelioration of living conditions, provision of services, communication transportation networks, as well as recreational spaces". It is therefore understandable that the planning and development of a humanitarian settlement must consider spatial dynamics and the services provided.

Looking more closely, Zivkovic J. [28] argues that a human settlement is a place where people live with all the social, material, organizational, spiritual and cultural elements. In this case, any form of human habitation, from the smallest house to the largest city, where people reside and pursue their life goals, can be understood as a settlement. At the same time, Ramadan [29] establishes an analytical reflection for the refugee space, focusing on Palestinian camps in Lebanon and concluding that a refugee settlement is a space of people, institutions, built environment with diverser interactions that produce values and practices. His analysis offers a way to ground our understanding of the importance of territory or space, and people's relationships with that territory for living and thriving. Until now, a humanitarian settlement has been considered as an isolated territory based on disjointed urban fundamentals [30]. But this view contrasts with a human settlement, which is seen as a complex social system to be planned and developed as such. In the Journal [30], Oesch L. demonstrated that there is another facet of urbanism in a humanitarian settlement: *"an urban planning apparatus of which state and non-state institutions are part, as the result of a balancing act that ensures the temporary character while allowing the implementation of a form of urban development that leads to a material homogenization with the surrounding urban space."* With an emphasis on social interactions, Brankamp H. [31] urges to explore the humanitarian settlement beyond its territorial capacity, but more as a place imbued with feelings, interactions and expression of people's needs. He emphasizes that despite their fleeting nature,

emotions and culture are also essential to understand the complex social fabric of the humanitarian settlement. Still regarding social complexities, García-Díaz states in his book, *The Design of Complexity* [32] that any complex system formed by human beings and taking into account the technical, human and social perspectives that are crucial to address social problems, is a social system. Thus, by attempting to reveal systematic ways to improve social systems, it offers a vision of social systems engineering that allows for the design of systemic interventions. His work has thus shown the importance of social systems engineering in human urban settlements to solve the various development problems they face, especially in terms of sustainability. He also explored the complexities of social systems in many fields, highlighting the benefits of applying systems thinking and tools to solve social problems, such as organizational systems, computational behavioral modeling. As such, a human settlement can be considered a complex social system, and the application of model-based systems engineering can help explore the dynamics related to various components of the system, including interactions and behaviors.

3.3.1. The Triple Nexus Framework in Perspective

Although few studies have examined the concept of the water, energy and housing nexus in social systems, some researchers have worked in specific areas that complement this research. For example, Yasmin et al. [33] reviewed the sustainability and resilience of water, sanitation and hygiene in refugee communities. They revealed growing concerns that sustainability depends on understanding the functions and interdependencies between these sectors, and acknowledged that there is no one-size-fits-all solution, and concluded that sustainability in one community may not be appropriate for others. Furthermore, they argued that the increase in refugee numbers and disparities in the provision of basic services will be exacerbated if not prepared for or mitigated by sustainable considerations. However, their work did not demonstrate how a systemic approach

could contribute to solving these problems. Similarly, Zhuang Y. [34] conducted a study on the integration of water and energy resources called water-energy nexus, through a system dynamics approach. While the study acknowledges that water and energy are intrinsically linked and dependent on each other in a human community, it does not highlight the importance of the territoriality in which water and energy systems develop and interact, nor the planning options that could shed light on different scenarios. On another point, by examining the integrated approach of the water-energy-food nexus, Al-Saidi M. and Elagib A. [35] attempted to identify possible ways to assess the interdependencies between the three resources using a policy framework. They found that while the water-energy-food nexus has been successful in changing policy debates, its prioritization seems to depend solely on policy makers, and governance issues have been overlooked. But to understand the integrative approach sought and which would contribute to optimizing for example, water, energy and food resources, Ghodsvali et al. [36] attempted to develop an integrated decision support system through a spatial optimization modeling based on a combination of methods for the planning of complex systems such as cities. The results could serve as guidelines, encouraging effective decision-making in integrating the water-energy-food nexus. Similarly, Mansour et al [37] looked more critically at the issue of global population growth in relation to excessive resources consumption that would lead to difficulties. They concluded that a sustainable solution requires a comprehensive examination of the availability, accessibility, quality and stability of these resources. This study adopted a multi-criteria approach to identify the linkages between water, energy and food resources in a holistic manner, rather than as separate elements. The advantage of this approach is that it takes into account the interconnections between the three resources, that creates synergies between them, but also prevents the transfer of problems from one sector to another by minimizing potential trade-offs [38].

Several studies have explored nexus concepts, for example in the fields of water, energy and food, sometimes using simulation tools [39], governance [40] or simply judicious implementation [41]. However, none of them have yet presented a critical analysis of the nexus concept in humanitarian contexts from a systems perspective. Among the most relevant works available in the literature, we can cite [39] which examined the water-energy-food nexus through methodological research questions, and recognizes the prevalence of pertinent related issues and data uncertainties. In addition, Ringler et al. [42] conducted a sustainability assessment across the water, energy, land and food nexus by exploring their interdependencies. At the end of these works, they came to the conclusion that resources are contributors to the desired sustainability, but in achieving it in a holistic perspective could ensure more balances and advantages in terms of investments. But again, these works did not explore the roots leading to inefficiencies, poor planning or unsustainability. Exploring the dynamics of the water-energy-land-food nexus over time, Amadei B. [43] introduced a multidimensional concept that advocates for the need to address data quality in a participatory manner, using system dynamic applications.

In the housing sector, there are few studies in the literature presenting a housing-water or housing-energy nexus, especially in humanitarian settings or underdeveloped community contexts. Nevertheless, in an attempt to provide insights into the potential effects of the housing on the nexus, Cheshmehzangi A. [44] analyzed the challenges and implications associated with the energy-housing nexus in China's wealthier transitional urban and peri-urban areas. But the study was limited to the implications of housing and energy policy reforms. Furthermore, from the interdependence perspective in the housing and water sectors, Meehan et al. [45] investigated access to water for the construction of housing in low-income communities. The study showed that poor access to domestic water should be seen as a housing issue reflecting structural

inequalities, particularly in cities where wealth gaps are widening to the detriment of low-income populations. In light of this, the study concluded by calling for more research and action at the intersection of water supply, housing and social inequalities, the so-called housing-water nexus. It noted that there is a correlation between water resources and housing, and that inequality issues persist, particularly in low-income areas that lack adequate infrastructure and where this link is not yet well understood. While a few studies have focused on the linkages between water, energy, land and food from rural and urban perspectives, a limited number have focused on housing sustainability without emphasizing the relationship between these elements and housing and, even more unfortunately, in humanitarian contexts. However, Dunga H. and Grobler [46] conducted a study to establish a relationship between food insecurity and housing insecurity in low-income neighborhoods in South Africa, using various statistical techniques based on a quantitative research method. Although the study was not conducted in a typical humanitarian context, it revealed that there is a trade-off between housing and food security and that in many cases, food insecurity and housing insecurity coexist. It argued that in any human context, affordable housing and food security are essential for development to ensure a healthy and adequate lifestyle. In the same context, Ostovar A. [47] studied the impact of hydrological conditions on housing development in the Monterey Peninsula. He examined the extent to which water could limit the development of affordable housing for low-income households. However, it only skimmed the surface of the housing and water situation on the Monterey Peninsula and did not describe it in detail, nor did it examine the detailed differences between jurisdictions, how best to implement the recommendations, or what some of the trade-offs might be. Finally, no study would be complete without taking into account UNHCR's long history of developing humanitarian settlements. The approach adopted for decades consists of applying standard site planning methods based on

identical spatial forms, without prior contextual, socio-spatial and territorial analysis and with the local environment in which they are implemented. Table 1 summarizes UNHCR’s minimum standards.

Table 1: Minimum Standard for Camp Planning (Adapted from [48])

Description	UNHCR Minimum Standard
Covered living area	3.5 sqm. per person minimum In cold climates and urban areas, more than 3.5 sqm. may be required (4.5 sqm. to 5.5 sqm. is more appropriate) Minimum ceiling height of 2m at highest point
Camp settlement size	45 sqm. per person
Fire Safety	30 m of a firebreak every 300 m Minimum of 2 m between structures – ideally 2 times the height of the structure
Gradient for camp site	As a guide 1% to 5 %, ideally 2% to 4%
Drainage	Appropriate drainage needs to be put in place, especially relevant in all locations that experience a rainy season.

Such an unplanned, unintegrated and inherently temporary approach to humanitarian settlement planning has been detrimental to the environment and has strained limited natural resources. The lack of coherence in the processing of operational data has exacerbated the problems and created difficult situations to encourage systemic approaches. For example, in 2023, UNHCR estimated that approximately 22% of the world’s refugee population is living in temporary settlements [48]. In view of this alarming situation, UNHCR has initiated some improved methods. However, it is observed that the approaches through which current humanitarian settlements operate are not integrated and lack a systematic view between components and data.

3.3.2. Efforts to Transition to Integrated Settlement Planning.

In an attempt to move away from the current approach, UNHCR has launched a number of initiatives in recent years. In 2013, UNHCR issued the Policy on Alternatives to Camps [49] to

avoid the creation of refugee camps, while seeking alternatives that find durable solutions. This policy guideline recommends exploring alternative ways of accommodating displaced people, who may be in local communities outside camps. While recognizing the unsustainable nature of current camp conditions, the policy has not addressed the specific issues undermining planning models and is therefore unable to prescribe the necessary integration mechanisms. In addition, the Master Approach to Settlement Planning [8] launched by UNHCR in 2019 has provided a framework for the design of humanitarian facilities. It established ten guiding principles that are aligned with national, sub-national, and local development plans. This framework facilitates efforts to link humanitarian responses to long-term development. However, the proposed holistic approach to needs assessment, which uses a variety of checklists and mapping models and decentralized data management during the planning stages, does not guarantee the ability to interrogate sectoral data that could lead to meaningful data integration to streamline balanced decision-making. While some attempts to apply the proposed guiding principles have led to significant progress, as in the case of the Kalobeyi settlement in Kenya [50], whose planning and development have facilitated the integration of refugees into host communities with improved access to social services and opportunities for self-sufficiency, it is commonly observed that this approach still fails to demonstrate or recommend precisely what needs to be done to ensure effective data integration across sectors to maximize the benefits at stake.

3.3.3. Data Management in Humanitarian Settlements

Over the years, organizational data management has become a kind of "ad hocism". This practice often results in a process of collecting data for specific purposes, then storing it in disparate databases, wasting time and duplication of effort when planning for subsequent years. These issues are well highlighted in the UNHCR's Evaluation Data Management Report mentioned

above. Indeed, the report reveals that UNHCR has a better method of collecting, storing, and sharing data across multiple systems. However, most data is collected in compartmentalized systems, and the exchange, sharing and pooling of data between systems is not yet carried out consistently. As a result, UNHCR is still faced with a fragmented approach to data management and processing and is still far from achieving the sustainability goals it has long sought.

3.3.4. Different Types of Data Used in Humanitarian Settlement

For the planning of humanitarian settlement, organizational data is generally classified into three categories: (1) administrative data, which concerns human resources and the supply chain, (2) financial data, and finally (3) operational data. Operational data management is the one concerned by this research and generally includes data on population, needs, and socio-economic data depending on the context. Figure 6 shows the categories of data used in humanitarian operations and illustrates how UNHCR handles parallel operational data in the water, energy, and housing sectors.

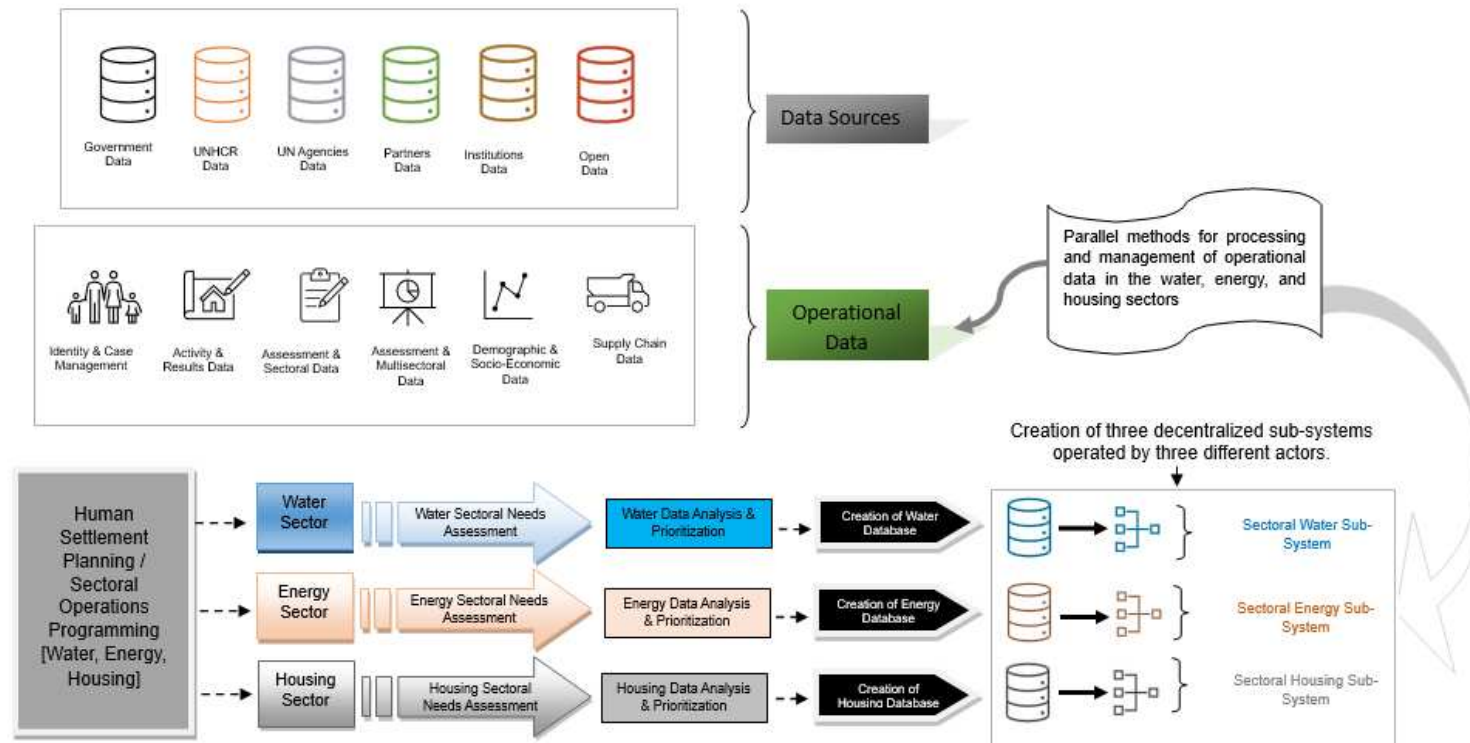


Figure 6: UNHCR Data Types showing a Decentralized Processing of Water, Energy, and Housing data [Adapted from [19)]

As shown in Figure 6, the three sectors of water, energy and housing each process data in parallel. This means that the same water, energy and housing data are collected from different sources almost simultaneously and in parallel, resulting in redundancy and the creation of three separate databases due to a lack of integration that would interconnect the process and optimize prioritization. The absence of such a systemic approach to data management has led to poor planning and development of humanitarian settlements. Stakeholders do not fully optimize different types of data for further analysis and, as a result, significant gaps have emerged as the current disaggregated approach generates unintended consequences that negatively affect the well-being of displaced people who have been excluded from the SDG frameworks [86]. There is a large set of sectoral data, but much duplication, which negatively affects the sustainability of humanitarian settlement planning and management. UNHCR and its partners recognize the necessity for a decision-support framework capable of integrating and systematizing multi-sectoral data from different sources through a unified system, better than the current conventional methods described in the literature.

This research addresses these gaps and introduces a Triple Nexus water-energy-housing framework as a new perspective on the integration of critical resources in humanitarian settlements. This research's focus on MBSE to streamline data processing in the water, energy, and housing sectors represents a significant advance in the field of humanitarian operations optimization. Indeed, the accelerating growth of displaced populations in humanitarian settlements augurs ever-increasing pressure on water, energy, and housing, which may lead to resource depletion, degradation of ecosystem services, and irreversible societal and environmental changes in the long term. Quantifying the interconnections between the energy, water and housing sectors would be a fundamental step towards integrated systems modeling, particularly sought-after in

humanitarian settings. To date, the literature shows that little work has been done to study the links between water, energy and housing in humanitarian contexts, and that each sector is still perceived, operated and measured separately. The effectiveness of water subsystem options for improving resource efficiency to reduce gaps is only examined in the context of the water system. Similarly, the efficiency of energy supply is only studied in terms of energy needs [33], while the efficiency of housing construction is only perceived as a need for housing.

3.4. Influencing Factors in Current Operational Data Management

Several factors influence the current management of operational data, in particular the lack of integration and the model-based systems approach to data management and processing.

3.4.1. Decentralized Approach to Operational Data Management

In recent years, UNHCR has undertaken a number of efforts to streamline data management processes, but the methods remain highly decentralized [19]. They are a variety of technical sectors that require significant amounts of data, but according to the Report [19], it does not have an integrated multisectoral data management policy and structure that provides a “rule book” on data standards that could bring consistency. As a result, there is evidence of duplication and inefficient and poor-quality operational data management and processing.

3.4.2. Lack of Data Sharing and Integration Systems

From a data processing perspective, UNHCR has traditionally not placed sufficient emphasis on developing a dedicated unified platform to ensure easy access to stakeholders and data consumers. There are few, if any, operational data-sharing platforms. Data collection efforts include the Micro-data Library [25] and the creation of the Joint Data Centre³ [51]. The

³ UNHCR in partnership with the World Bank has created the Joint Data Centre (JDC) on forced displacement in Copenhagen. The JDC focuses on collecting, analyzing, and disseminating anonymized micro data which includes

commitment to creating integrated and automated operational data platforms that are readily accessible and usable by various stakeholders remains a challenge that has yet to be addressed. As no such platform exists, and to fill this gap, a few UNHCR country offices are trying isolated practices by creating integrated data service units, with documented cases in the Middle East and North Africa region. The lack of harmonized practices and a history of unsuccessful initiatives call for a much more integrated and comprehensive standardization of operational data accessible to a wider audience.

3.4.3. Efforts to Automate Data Management in Integrated Human Settlements.

For successful operational data integration and processing (i.e., collection, controls, analysis, and transformation), the most successful example is the PRIMES⁴ data system, which envisages the UNHCR Data port⁵ as a repository automatically populated with registration data. There is also the Operational Data Portal⁶ for public statistics on displaced populations, the Data Entry and Exploration Platform (DEEP)⁷, which offers a series of tools designed to 1) analyze structured and unstructured qualitative data and 2) filter qualitative data according to the specifications of the user's analytical framework. However, these platforms still lack automated

household-level socioeconomic data such as income, consumption, skills, health status, and economic activity. The JDC facilitates open access to these micro data, with adequate anonymization and safeguards to protect persons of concern and the integrity of data collected.

⁴ The term “Population Registration and Identity Management EcoSystem” (PRIMES) encompasses all interoperable UNHCR registration, identity management and caseload management tools and applications (existing ones, such as proGres and BIMS, as well as those developed in the future).

⁵ UNHCR Dataport is an inventory of UNHCR’s current population information with real-time connectivity to proGres v4 which pulls population data from proGres v4 and organizes the records with the help of indicators and attributes that cover all thematic, sectoral, and case management areas. It’s a tool which maximizes the potential of the data collected by UNHCR and provides a quality resource for analytical and comprehensive information on persons of concern and contribute to global intelligence on displacement.

⁶ The UNHCR Operational Data Portal is available from: data.unhcr.org

⁷ Data Entry and Exploration Platform (DEEP) offers a suite of tools and collaborative workflows that meet the needs for compiling, storing and structuring data and qualitative information, that was initially established in 2016 in the aftermath of the Nepal Earthquake to strengthen collective sense-making and analysis.

integration systems approaches that would enable meaningful data integration required for multi-sectoral functions or efficient and sustainable services.

3.4.4. Efforts to Improve Operational Data Management

While data collection is imperative for human settlement planning management, it is equally important to ensure that data can be adequately disseminated among stakeholders through a secure, integrated, and unified platform easily accessible. To this end, this research aims to introduce a novel operational data management framework that highlights the effectiveness of an instrument based on a triple nexus paradigm. This framework is intended to mitigate the risks of duplication while fostering greater collaboration and trust among different stakeholders.

Indeed, UNHCR works with a broad audience, and data sharing is often organized through various agreements. The global data-sharing agreement with the World Food Programme (WFP) is one example. The principle is that these agreements specify the processes and responsibilities for sharing data and its use. Another example is UNHCR's partnership with the World Bank, which led to the creation of the Joint Data Center (JDC) on forced displacement, focused on the collection, analysis, and dissemination of anonymized micro-data [51]. The JDC facilitates open access to micro-data, with adequate anonymization and data integrity. Unfortunately, the process stops at this level and does not allow users to establish further linkages with other types of data or other segments of humanitarian settlement systems.

3.5. Application of Systems Engineering (SE)

To address these aforementioned issues, this research defines a human settlement as a system within the broader landscape in which it is embedded. This involves identifying the key elements that make up a system and how they relate to each other, the capacity they exert on the processing of operational data, and the need to model such a system to understand their

complexities and behaviors. Applications of SE and Model-Based Decision Making theory are also examined to propose a Triple Nexus Framework to facilitate the combination and sharing of operational data. This research demonstrates the capacity of such a model to generate composite data from the three sectors of water, energy, and housing and make them accessible to a wider audience and decision-makers.

3.5.1. Human Settlement System and Systems Engineering Perspective.

This research argues that the application of SE to human settlement system will enable efficient improvement of current challenges encountered in humanitarian operations. It introduces SE as a new approach in the context of humanitarian landscapes, to define an innovative methodology and perspective, relatively unexplored in current practices. While the effective and sustainable performance of human settlements depends on a multi-sectoral dataset, the complexity of organizing such a dataset has discouraged the adoption of a holistic approach to gain knowledge on sustainable human settlements. SE provides a method that can facilitate the systematic organization of the components and interrelationships of such a system to be conceptualized and developed differently.

The literature presents different definitions depending on the context. This research applies SE approaches, and considers the settlement system as an integrated entity and focuses on the capacity of its subsystems to perform needed functions, and generate meaningful operational data. MBSE) methodology SysML are applied to develop a typical integrated human settlement system to obtain a deeper illustration of the system. This research identifies six sub-systems as integral components of the overall system. An initial validation of the system functionality is performed based on two scenarios: the system's capacity to efficiently process a mega dataset in real-time mega and an optimization simulation to improve the system's performance as measured using a

triple nexus metric. Further validation is provided through a case study, which focuses on integrating the system's capacity to provide services that meet stakeholder needs.

3.5.2. Triple Nexus Framework and Systems Engineering Perspective.

From a SE perspective, the Triple Nexus Framework goes beyond the traditional sectoral approach. While the current approach is decentralized, the proposed Triple Nexus identifies mutually beneficial responses based on understanding the synergies between water, energy, and housing properties. It also provides an informed framework for determining trade-offs and synergies that maintain the integrity and sustainability of the system in which it unfolds. The Triple Nexus Framework is a generalizable tool that allows the use of composite datasets to establish the priorities required for multi-sector programming.

3.5.2.1. Theory of the Triple Nexus: Water-Energy-Housing

The Triple Nexus approach stems from the fundamental requirement to integrate data from the water, energy and housing sectors (Table 2). With the traditional sectoral approach, attempting to achieve sustainability of resources and services independently often jeopardizes the sustainability of one or more other sectors. The Triple Nexus approach enables synergies and trade-offs to be made to achieve sustainable outcomes and reduce system impacts and risks.

Table 2: Multi-Dimensional Interlinkages Between Water, Energy, and Housing

Water <-> Energy: Water plays a critical role in energy production, for irrigation, in hydroelectric plants, for cooling thermal plants and in growing plants for biofuels. Conversely, energy is required to process and distribute water, power water supply equipment (solarization), pump and treat groundwater, etc...

Water <-> Housing: Water is the keystone for housing construction and repairs, housing needs, concrete and bricks production, etc... Conversely, agricultural intensification for households' activities impacts water quality.

Housing <-> Energy: Energy is essential to life and comfort of the home. It is needed for lighting, heating, cooking, and income-generating activities. It is an input throughout the home's construction, from pumping water to processing, transporting, and refrigerating food in the house.

Integration between water, energy, and housing is an essential requirement for the sustainability of all the above. It is negatively affected if water, energy, or housing are unsustainable within the urban planning subsystem and the integrated human settlement.

3.5.2.2. Triple Nexus Framework (TNF)

The Water-Energy-Housing Triple Nexus Framework aims to better organize the mutually beneficial integration of the water, energy, and housing sectors. The characteristics and interrelationships of this nexus are defined by applying the MBSE methodology, which provides a systemic approach to tackling inefficiencies in the management of these resources with a view to the sustainability of the system. The significance and novelty of the TNF is that it enables researchers to introduce a new perspective on the integration of water, energy and housing in humanitarian settlements. The focus on MBSE is beneficial in that it allows researchers to define data processing and relationships between the water, energy and housing sectors, representing optimization of humanitarian operations in a way that has never been done before. The nexus data platform is the final step in the process, providing consolidation and access to a significant set of data across the three sectors. Figure 7 and Figure 8 show schematic representations of TNF data processing. Data from water, energy, and housing are processed, analyzed, and consolidated using a single process. The creation of composite data or indicators that interrelate the properties of the three sectors is designed to maximize mutual benefits. A single nexus database and centralized platform are then created to store all data simultaneously and make it available to consumers.

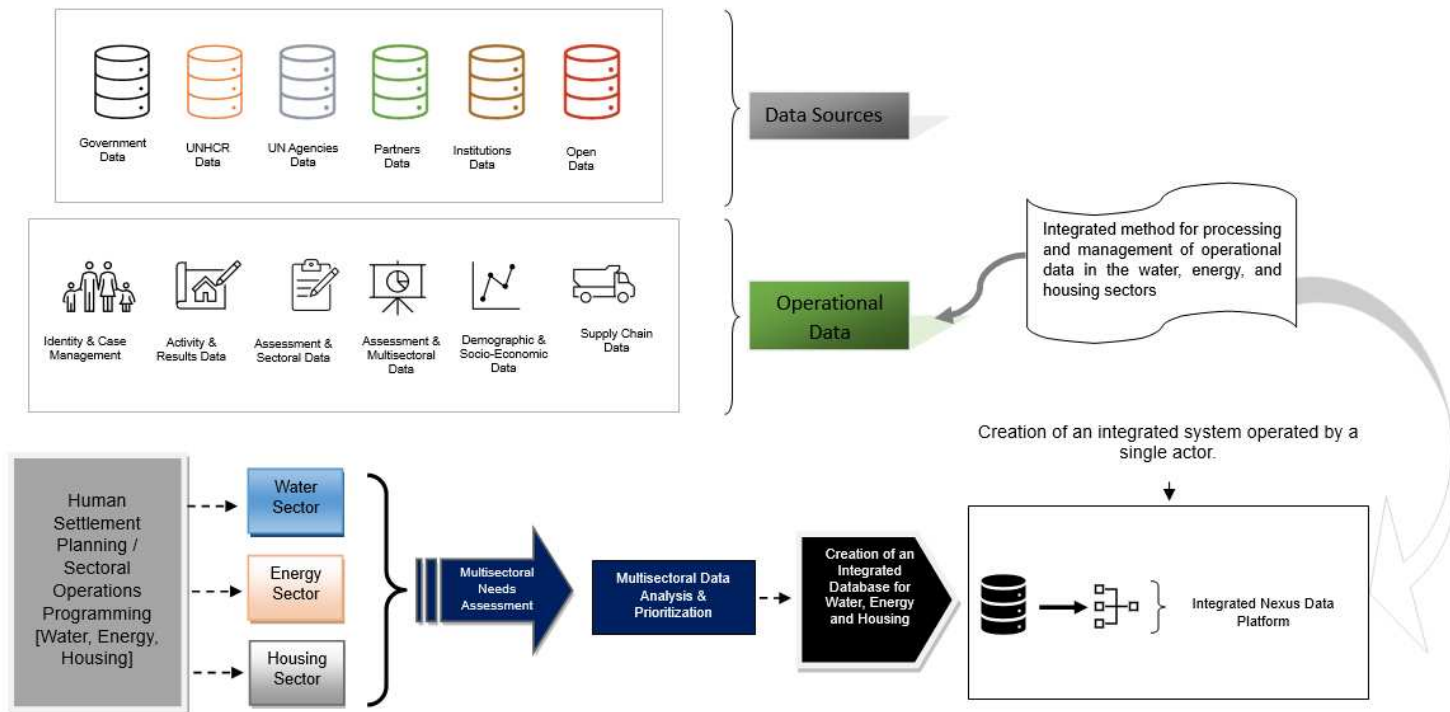


Figure 7: Schematic Representation of the Triple Nexus Processing

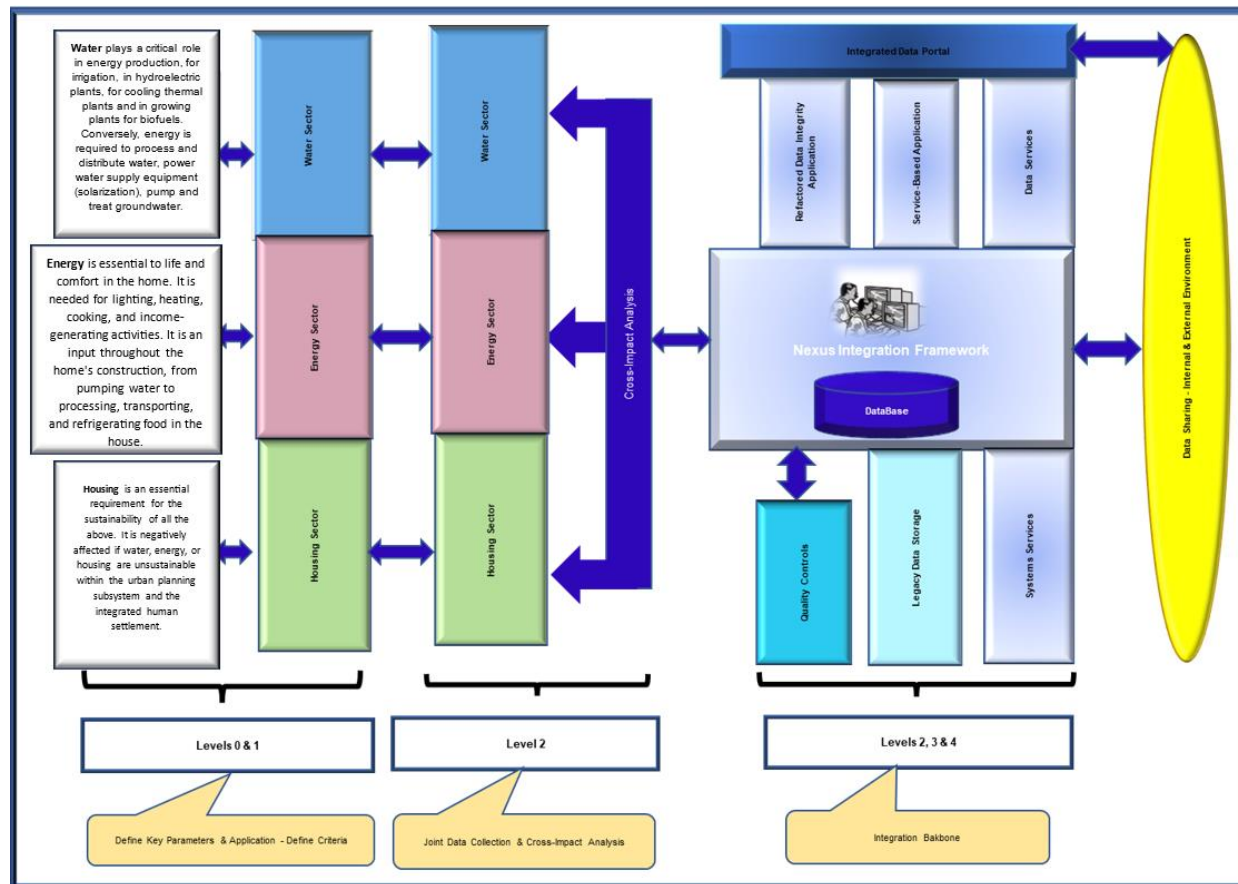


Figure 8: Schematic Representation of the Triple Nexus Framework Operations

3.6. Conclusion

In answering Research Question 1, this research calls for a literature review and an examination of current approaches to integrated human settlement planning from an operational data management perspective. The answer to Question 1 defines the concept of Integrated Human Settlement System and the Triple Nexus Framework, and identifies the main shortcomings encountered by settlement practitioners.

The literature review revealed that much of the scientific community has embraced the human settlement concept and the nexus approach as an integrated approach to sustainable planning and service delivery. However, many studies agree that there is as yet no universally accepted concept of nexus, and its application in humanitarian contexts to date has created a large gap that needs to be filled. The answer to Research Question 1 presents Model-Based Systems Engineering (MBSE) as the most appropriate methodology for streamlining data processing in the water, energy, and housing sectors, representing a valuable contribution to the optimization sought in humanitarian operations. The result provides a foundation for understanding the organization, functions, and attributes of an integrated human settlement, as well as aspects of Systems Engineering that could be applied to address a critical and underexplored area of the nexus and to understand the complex interdependencies that different sectors bring to the development of humanitarian settlements.

Using UNHCR's current operational data management approaches, specific research contributions include the design of a novel Triple Nexus Framework with the potential to significantly improve the design and management of human settlements towards more sustainable practices, aligning with current global priorities.

CHAPTER FOUR: MODEL-BASED SYSTEMS ENGINEERING (MBSE) AND SYSTEMS MODELING LANGUAGE (SysML) APPLICATION TO THE CONCEPTUALIZATION OF A HUMAN SETTLEMENT SYSTEM AND A TRIPLE NEXUS MODEL

The purpose of Chapter 4 is firstly to conceptualize and define the Integrated Human Settlement System and to apply Systems Engineering (SE) methods to design the new system and the Triple Nexus Framework.

The research objectives of this Chapter are captured in the form of Research Question 2 as stated below.

4.1. Research Question 2 – *Can Model-Based Systems Engineering (MBSE) methodology effectively conceptualize and model an Integrated Human Settlement System and Triple Nexus Framework to address critical and current challenges?*

To answer Research Question 2, Chapter 4 conducts a literature review to better understand the concept of integrated human settlement and how it can be viewed as a system. To this end, this Chapter uncovers what motivated the concept, how it is defined, what are the subsystems that construct an integrated human settlement, and the issues related to processing mega-dataset.

4.2. Definition of the Concept of Sustainable Human Settlement

The concept of Integrated and Sustainable Human Settlement has become a priority and is rapidly gaining prominence on the agenda of sustainable development as a promising solution to the challenges facing human settlements. However, due to its complexity, the concept still lacks a universally accepted definition. An integrated, sustainable human settlement is defined based on a thorough literature review to provide an interdisciplinary synthesis in line with the objectives set

for this research, focusing on the interconnections between interdependent components essential to achieving sustainability goals. The underlying arguments are often that human settlements themselves are complex, in line with sustainability perspectives. In recent decades, many researchers and practitioners have sought to develop various models of human settlements that can contribute to and enhance sustainability. Compact and green cities [53] are the most widespread sustainable city models. However, the challenge remains to encourage urban planners, as well as humanitarians and policy-makers, to collaborate more closely on other reorganizations of urban areas, particularly about the integration of infrastructure and the built environment, as well as economic, social, and cultural dimensions. To this end, Bibri and Krogstie [54] have argued that a sustainable human settlement could be an urban form that seeks to achieve a certain level of sustainability by enabling urban systems such as infrastructure, ecosystem services, human services and administration to function constructively. In addition, recent research efforts have begun to focus on integrating various elements into human settlements to enhance sustainable models. One scenario has been the integration of urban development perspective and strategies to achieve a level of sustainable functions and services. This holistic vision has shown great promise in addressing the challenges associated with urban sustainability or in providing solutions to achieve it [55]. Other efforts have refined the definition of the concept of linking the different elements of a single but larger system that functions as a whole. In this respect, The Hague Academy of Local Governance [56] explains the integration process as a planning approach based on large-scale, holistic initiatives involving multiple stakeholders in different sectors and at different levels, and linking them functionally. In a comparative reflection on the "smart city concept", Yang C. [57] has defined a smart city as an integrated sustainable urban settlement in which everything is connected, with an emphasis on sensor-based data collection and management.

Other recent research [58] has explored the field of sustainable cities, focusing on identifying urban domains associated with important dimensions such as infrastructure, energy, the environment, mobility and accessibility, social services, and public safety. All this raises the question of the extent to which a human settlement can facilitate the connection of different sectors to produce sustainable results through an integrated data platform.

Our analysis proposes three groups of definitions. The first group of definitions focuses on data sharing, interconnectivity, and interdependence, as mentioned in Chapters 2 and 3 (Table 3). The second group describes the concept based on economic growth and service provision (Table 4), and the third group focuses on human resources, i.e. the people living in the system (Table 5).

Table 3: Definition of a Human Settlement with Data Sharing, Interconnectivity, and Interdependency Perspective.

Definition	Reference
Makes use of all available resources to create an integrated and sustainable urban environment that is more livable.	[59]
A city in which everything is connected by using data collected and gathered by sensors.	[57]
Using advanced and integrated materials such networks of computerized systems (databases, tracking and decision-making algorithms).	[60]
Advantage of communication integrated into cities' infrastructures to optimize daily operations of life and, at the same time, improve everyone's quality of life.	[61]
The operation of a city, its efficiency, and the quality of life of its citizens are improved and enabled by data information technology.	[63]
Technology makes citizens more informed about what happens in the city and allows a city to be more efficient and interactive.	[64]
Enhance urban performance using information technology, information, and data.	[65]
A city where innovation based on technology is used in its development, planning, and operation.	[66]

Table 4: Definition of a Human Settlement from Economic Growth and Service Delivery Perspective (ex: Water, Housing, Energy, Economic, Social)

Definition	Reference
It is a community in which data and information are extensively deployed as stimulus to decision making and finding solutions to social needs.	[67]
There are cities that have the best quality of life and their citizens have the best economic wellbeing.	[68]
A city that provides an environment to a happy and healthy community despite challenging global conditions and trends that might be brought by social, economic, and environment.	[69]
A city that combines economic, social, and environmental growth, and it interacts to promote social and urban development by improving the economy, the participation of people and effective governance.	[70]
A city that performs well in governance, economy, people, living, environment, and mobility.	[71]

Table 5: Definition of a Human Settlement from Human Resource (Populations) Perspective

Definition	Reference
An environment which prioritizes human capital while developing collaboration.	[72]
An urban city that provides an environment to a happy and healthy community despite challenging global conditions and trends that might be brought by social, economic and environment.	[69]
Areas that are equipped with high potential of learning and innovation. They are developed through citizens' creativity and institutions that build and manage knowledge and associated infrastructure.	[73]
Make a living space that is more accessible, safe, competitive, profitable, open, and transparent.	[74]
High knowledge-intensive workers, a planning process that is output-output oriented, and initiatives that valorize sustainability.	[75]
Urban framework in which people become more integrated into city life.	[76]
People with social interaction in with respect to integration, public life, and openness towards the wider world.	[77]
Highly urban environment that serves businesses, organizations and people's needs.	[78]
A settlement with significant capacity to address many socio-economical and technical aspects of development.	[79]

A thorough analysis of these three thematic definitions led to the adoption of a harmonized definition of the concept within the framework of this research, presented in the following Sections. The characterization of sustainability as a centrality of such a system is examined in the third Research Question.

4.3. Integrated Human Settlement Concept Definition

Although the search for an established definition could be assimilated to that of an urban city or a smart city [4], the definition of the concept of integrated human settlement is based on broader dimensions and components. These components represent its central subsystems and their consideration is crucial to define it well. By correlating the three thematic definitions, I assert that an integrated human settlement concept would achieve the following three results:

- (i) seamless integration of all components into a single system that functions holistically as a whole;
- (ii) effective interconnection between components to produce collective outcomes of high performance;
- (iii) meaningful data flow through a single data platform for efficient and uninterrupted service delivery.

Thus, the concept will focus on meaningful operational data processing between components or subsystems and the capacity to deliver efficient and uninterrupted service to stakeholders. Based on this, I proposed the following definition:

“A system derived from stakeholder requirements that processes organizational data on an integrated platform, enabling an uninterrupted flow of meaningful data and information that produces sustainable real-time services to better serve displaced populations”.

4.4. Integrated Human Settlement System Architecture

Based on the above definition, the conceptualization of integrated human settlement presents a complex system composed of six vital interrelated subsystems. On the one hand, from the literature review and the works of many researchers, and the other hand, the review of most recent strategic documents of the United Nations [11, 26, 80, 81, 82, 83, 84, 85], Figure 9 presents a representation of the Integrated Human Settlement System with the six subsystems identified as pertinent for this research.

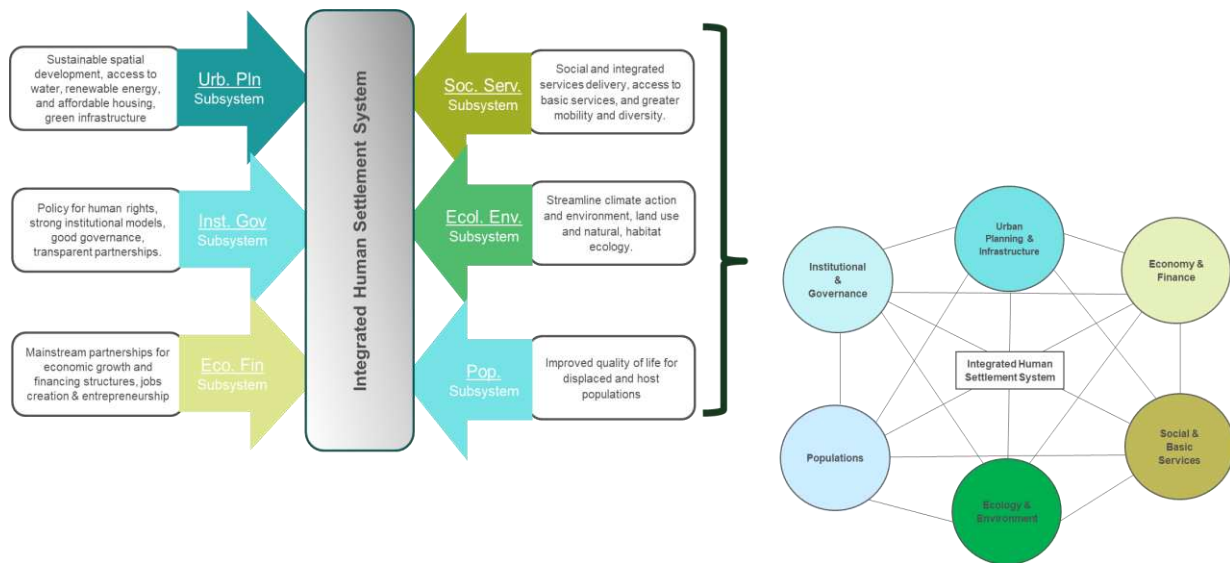


Figure 9: Representation of the Integrated Human Settlement System

Table 6 describes the six sub-systems of the proposed integrated human settlement system.

Table 6: List of Sub-Systems of the Integrated Human Settlement

Sub-systems	Description	Components
Urban Planning & Infrastructure [3, 11, 87]	Land use in line with policy and institutional frameworks. Sustainable built environment and access to services and technical network. Balanced rural and urban areas development.	<ul style="list-style-type: none"> - Land use and infrastructure - Water - Energy - Housing
Institutional & Governance [11, 87]	Relevant nstitutional arrangement as the basis for a good governance. Partnership and engagement with stakeholders at national, regional, and local levels.	<ul style="list-style-type: none"> - Institutional - Governance - Partnership
Social and integrated services [11, 87]	Integrated and equitable social services. Inclusion and diversity promoting participation and accountability, culture, heritage and marriages.	<ul style="list-style-type: none"> - Social inclusion - Integrated services
Economy & Finance [11, 87]	Economic growth for the creation value-added businesses and supply chains. Employment and entrepreneurship. Skills development and leasing opportunities.	<ul style="list-style-type: none"> - Economy and finance - Entrepreneurship - Jobs creation
Ecology & Environment [11]	Biodiversity and natural resource management. Balanced growth, regulation and climate actions.	<ul style="list-style-type: none"> - Environment and climate actions - Natural resources
Populations [3, 87]	People-centred planning and development. Participation in and access to data and information.	<ul style="list-style-type: none"> - Displaced people - Host community

Table 6 presents a description showing the integrated human settlement consisting of the six subsystems fully integrated with each other and vice versa. The integration dimension is effective when the six subsystems are well linked and interrelated. However, in the process of human settlement development, which is too often underpinned by preliminary, transition and development phases, it is evident that the six subsystems cannot be developed at the same scale. An effective scale of development and integration can be progressive and staggered. In this way, some subsystems could be integrated to respond more quickly to specific needs, and so on. Therefore, this sequential evolution in human settlement development requires the recognition of

different integrated-development scales, from the lowest to the highest, which is the one sought for this research, as shown in Table 7.

Table 7: Level of Subsystems Integration (Adapted from [69, 88]).

Levels	Subsystems integration in a human settlement
1 st level	Complete level of integration when the six subsystems are fully integrated
2 nd level	When five subsystems are fully integrated with the others.
3 rd level	When four subsystems are fully integrated with the others.
4 th level	When three subsystems are fully integrated with the others.
5 th level	When only two subsystems are fully integrated with the others.
6 th level	When only one subsystem is fully integrated
7 th level	Non-integration

4.4.1. What Makes a Human Settlement an Integrated System?

The definition of integrated human settlement with its six subsystems illustrates the complexity of such a system and its multidimensionality. From this definition, six levels of integration are considered (Table 7). Based on this, I defined a truly integrated human settlement as one that functions well in all six dimensions of integration, namely urban planning and infrastructure, institutions and governance, social and integrated services, economy and finance, ecology and environment, and people. Therefore, this research asserts that a human settlement is integrated if it is designed and well planned as a system and fully equipped with the key subsystems that provide the required services, including the capacity to command meaningful processing of a data stream that stakeholders consume. For the purpose of this research, a human settlement is considered integrated if it consists of the following six subsystems: (1) urban planning and infrastructure; (2) institutions and governance; (3) social and integrated services; (4) economy and finance; (5) ecology and environment; and (6) people, that work together on an integrated platform. This platform would serve as a catalyst to streamline and improve integration at all levels and

datasets processing, enabling the system to be effective and efficient across the six integrated subsystems.

4.5. Research Gaps

As stated in previous chapters, to function and achieve the desired sustainable results, all subsystems must be interconnected, interdependent and integrated [88] and take into account a systemic view of the entire settlement system. It has been argued that the integration of conventional systems is one of the only effective ways to address the unpredictability of the urban environment [89]. With respect to the present research, it has been observed that UNHCR attempted to adopt an integrated approach to human settlement planning and development. However, the lack of a holistic and systematic view has led to contrasting results and disconnection of elements and sectors, thereby compromising the desired systematic state which, as stated earlier, must have all elements integrated, interdependent and functioning seamlessly as a whole. This research attempts to address these issues by focusing on interconnectedness and interdependence by integrating the subsystems of the overall system and incorporating operational data generated from various sources both homogeneous and heterogeneous and processing them through a unified platform [90]. The absence of such a unified platform has led to identified shortcomings and justifies the necessity for a complex and integrated model [19].

UNHCR's current approaches to settlement planning and management have failed to provide an integrated system. This work generates a methodology for modeling the system and presents an integrated human settlement system that addresses related issues such as dataset processing and flow, and capacity analysis. The modeling of the human settlement system and the triple nexus framework based on MBSE and SysML methodologies, as well as the evaluation of

its capacity, are explicitly demonstrated in the following chapters. The design of the proposed triple nexus framework is presented in Section 6.6.

4.6. Conceptualisation of an Integrated Human Settlement System using the Model-Based Systems Engineering (MBSE) Approach

The concept of integrated human settlement, its scope and context of application have been defined in the previous chapters. This Section applies the SE method and presents an initial conceptual model of an integrated human settlement system. To achieve this, MBSE and SysML are used among the most appropriate applications capable of capturing the complexities of such a system and modeling as an integrated system. This Chapter defines and describes the SE approach, MBSE methodology and SysML applied in the initial conceptualization of the integrated human settlement system.

4.6.1. Context of MBSE and SysML

An integrated human settlement is defined as a complex system, requiring the application of SE in a social context [32]. Thus, in the application of MBSE and SysML tools, this research also drew on the perspectives of Social Systems Engineering (SSE). The literature reveals that the application of social engineering system dates back to the 1970s, uniquely reflecting engineers' views on social systems. In [32], social engineering is defined as the application of systems engineering concepts to social problems. It also defines a social system as any complex human-formed system that considers technical, human, and social perspectives essential to solving complex problems. This provides specific frameworks on how SE can be very useful in various domains, such as urban, health, socio-economic, and environmental systems. Human settlements are complex and multidimensional. By adopting an SSE approach, the complexity of human

settlement systems can be sorted without fragmentation and disconnection between subsystems. The application of MBSE and SysML will improve communication between system components and stakeholders and provide comprehensive system modeling for integration and sustainability.

4.6.2. Social Systems Engineering (SSE) Approach

In defining SE, Kossiakoff et al [91] define it as the application of engineering principles and approaches to successfully realize a complex set of interdependent elements working together toward a common goal. In their book [91], they emphasize that ‘*a complex engineered system is composed of a multiplicity of intricately interrelated diverse elements and requires systems engineering to lead its development*’. This definition is consistent with the that given by the International Council of Systems Engineering (INCOSE) [92]. Indeed, INCOSE defines SE as an interdisciplinary approach that allows to realize successful systems, a technique, or a set of best practices to manage circumstantial complex problems. Four processes of SE are described in [93]: comprehensive (consider the system an integrated whole), iterative, logical sequence of processes and activities, and transformation of operational needs into a form of parameters and preferred configurations. Viewed from this perspective, SE can realize a representation of the sequence of processes and methods applied to the design, development, integration, and testing of a particular system. The most well-known SE V-diagram emphasizes top-down functional decomposition, ultimately allocating requirements to subsystems and components, followed by a bottoms-up integration and testing sequence to build up the final system [94]. Figure 12 represents the SE V-diagram that provides a view of the process flow with sequences of steps that are often iterative to show the development of the life cycle with explicit relationships between requirements and systems and subsystems, and the developed and validated system [94].

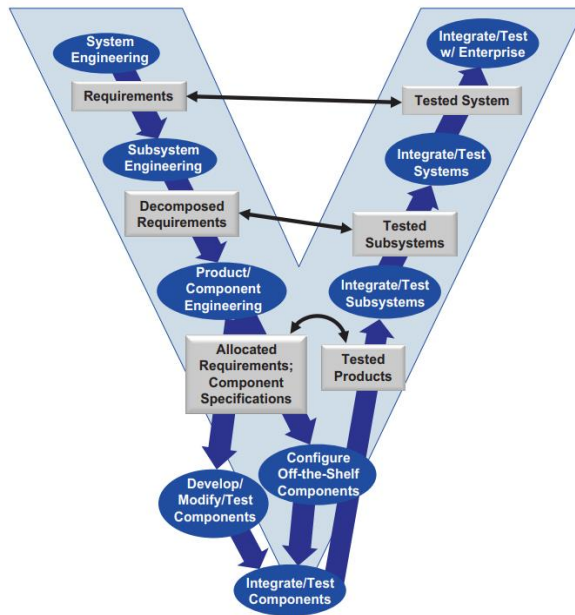


Figure 10: SE V-Diagram Representing Requirements Analysis and Allocation followed by Design, Integration, and Test to Realize the Final System. Adapted from [94].

Among the SE approaches found in the literature that would be useful for this research are the ‘‘Flowchart’’ which presents the main inputs and outputs of each of the system development stages and the relations among them in the system life cycle, illustrated in the form of a flowchart (Figure 11) and Boehme’s Spiral Model [95], (Figure 12).

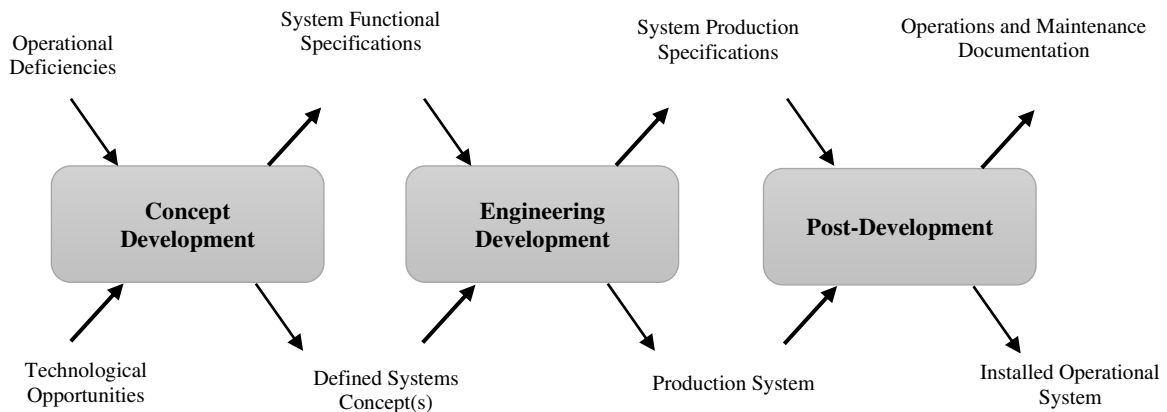


Figure 11: Flowchart showing the Principal Stages in a System Life cycle. Adapted from [93]

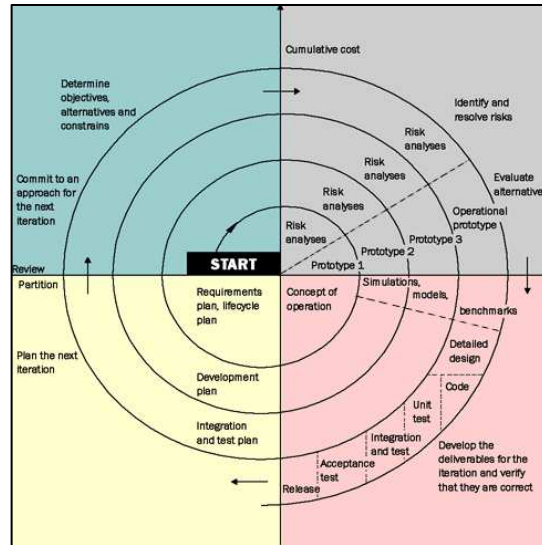


Figure 12: Spiral Model (Adapted from [95])

Understanding SE approaches focused on designing a high-performance system that meets the system requirements throughout its operating life-cycle will guide its application in human settlements. In the context of this research, understanding such a comprehensive, iterative process is the starting point for responsively and expertly modeling the human settlement system.

4.6.3. Systems Engineering (SE) Process

Friedenthal [96], an industry leader in MBSE, defines a system as a set of elements that interact with each another and can be considered as a whole interacting with its external environment to achieve a goal. SE is a multidisciplinary approach to developing balanced system solutions in response to the diverse needs of stakeholder. According to Friedenthal, a simplified view of SE technical process can be described as shown in Figure 13. The system specification defines the system requirements that address stakeholders concerns and assigns them to system components. The components are designed, implemented, and tested to ensure that they satisfy the requirements. The system integration and testing process includes activities that integrate the components into the system and perform the necessary checks to meet the requirements. These

processes are performed iteratively throughout the system development, with continuous feedback. In more complex applications, multiple levels of system decomposition begin at a system of systems level. In these cases, variations of this process are applied recursively to each intermediate level of design up to the level at which the components are built.

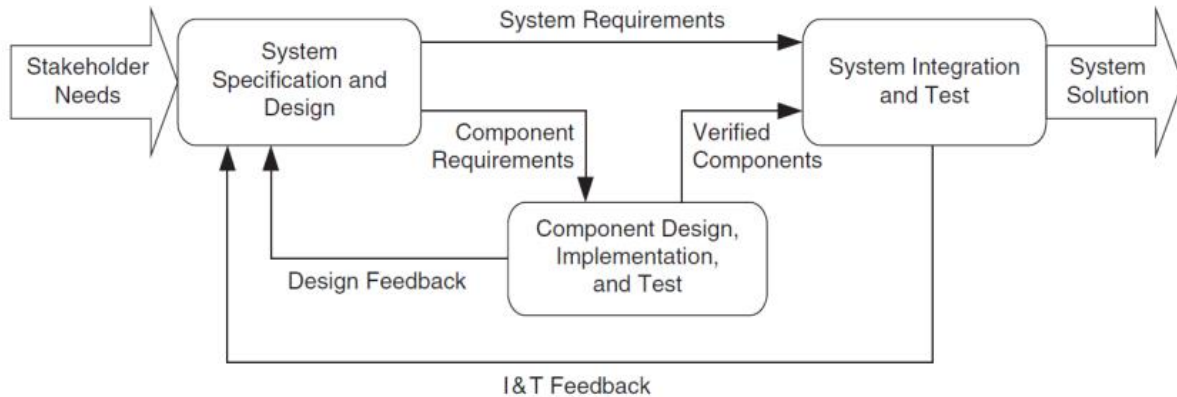


Figure 13: Simplified System Engineering Technical Process (Adapted from [96])

4.6.4. Model Based Systems Engineering (MBSE)

MBSE is fundamentally a forward-thinking process [97] that enables SE to be applied efficiently and consistently across the SE lifecycle. As systems become more complex, MSBE has been developed to cope with complexities to ensure traceability during the systems' development process. MBSE originated from the need to capture the system's functionalities rather than disconnected considerations, and the most accepted definition is from INCOSE. INCOSE defines MBSE as a formal application of modeling to support a wide range of systems engineering activities, including requirements definition, design, analysis, verification, and validation [98, 99]. These activities start in the conceptual design phase and continue throughout development and later life cycle phases [92].

This process, which starts at the highest and most general level, with the problem statement, i.e. the system-level requirements that need to be met, is analyzed and translated into functional behaviors that the system performs to meet those requirements. Behaviors are assigned to system components represented by architectural features, which provide the means for performance realization. The architecture is then tested to verify that the performance satisfies the requirements [99]. Accordingly, a layered structure takes shape as the system is developed in increasing detail. The engineering process follows these layers, penetrating deeper and deeper into the system design. Each iteration of the SE process increases specificity, removes ambiguities, and resolves unknowns. The domains (requirements, functional behaviors, architecture, validation, and verification) are all addressed in context at an increasing level of detail as one moves away from successive layers. So, just as the current approach executes the same traditional document-centric interventions in each domain to completion, SE and layered MBSE approaches work on each domain directly in each layer and iteratively. Figure 14 represents a simplified visualization of the two methods.

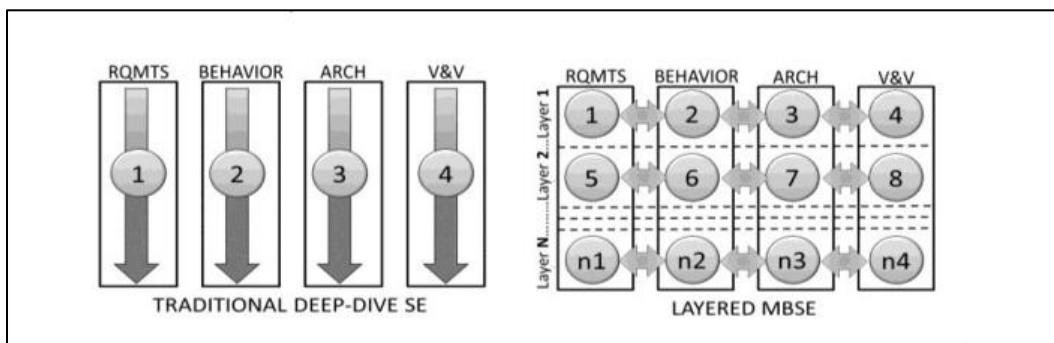


Figure 14: Simplified Visualization of the Layered MBSE Iteration (Adapted from [99])

4.6.5. Why Model-Based Systems Engineering (MBSE) Methodology for this Research?

MBSE methodology is closely related to the SE processes that occur during the life cycle of a system, often represented in a “V-Diagram”. The advantage of applying the MBSE

methodology is that all system-related data is stored and managed in a way that allows the interconnection of all subsystems of the system, which is more robust and efficient due to automatic change tracking and error identification. Based on MBSE and the simplified SE visualization methods in Figure 14, it is observed that while the traditional document-centric approach can lead to errors and complications in system design and management, the layered MBSE approach provides an environment that supports system development for analysis, design, evaluation, requirements verification, and consistent verification [99]. On the other hand, MBSE has the potential to overcome the deficiencies and practices affecting the design and architecture of systems [93], to facilitate the challenges of system integration [99] and to reduce the time of searching for data and information and assembling reports [99, 100], with a sharp increase in the management of system requirements. It also facilitates the collaboration between stakeholders from different disciplines for planning, design and development of systems, etc.

In conclusion, MBSE has advantages for systems engineers that facilitate traceability, data management, better collaboration between system stakeholders, automated configuration and management for different methodologies. All these elements allow to address and process the complexities of systems efficiently and provide support throughout the systems' life cycle.

4.6.7. Model-Based Systems Engineering (MBSE) Methodology

The SE process defines the activities to be performed, but generally does not provide details on how to implement them [101]. SE methods describes how the activities are performed and the types of SE artifacts produced. A methodology can be defined as a set of related processes, methods, and tools that can be applied to a class of problems that all have something in common [102]. For example, SE methods are identified in survey of MBSE methodologies [99], which include Harmony, the Object-Oriented Systems Engineering Method (OOSEM), the Rational

Unified Process for Systems Engineering (RUP SE), the State Analysis method, the Vitech Model-Based Systems Engineering Method, and the Object Process Method (OPM) among others. The specific criteria for applying a method vary from and may also depend on the purpose of its use, internal standards of Organizations. Among the most commonly considered important criteria are ease of use, ability to address SE concerns, and tool support level.

To achieve this and fully exploit the potential of MBSE, this research adopts the use of SysML, which is suitable to support many different SE methods, as well as functional analysis, which is a kind of structured SE analysis method. For scenario-based top-down analysis, the Object-Oriented Systems Engineering Method (OOSEM), which is an object-oriented method [94] and activity processes consistent with the “Vee” process. The model-based approach uses OMG SysML to support system specification, analysis, design, and verification [92]; OOSEM methods help capture and analyze requirements and design information for complex systems; integration with object-oriented (OO) and other engineering methods support system-level design evolution. As stated above, OOSEM is a hybrid approach that leverages object-oriented techniques and a SE foundation, as indicated in Figure 15 adapted from [92].

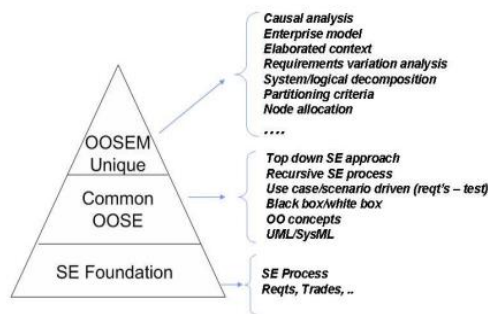


Figure 15: OOSEM Foundation (Adapted from [92])

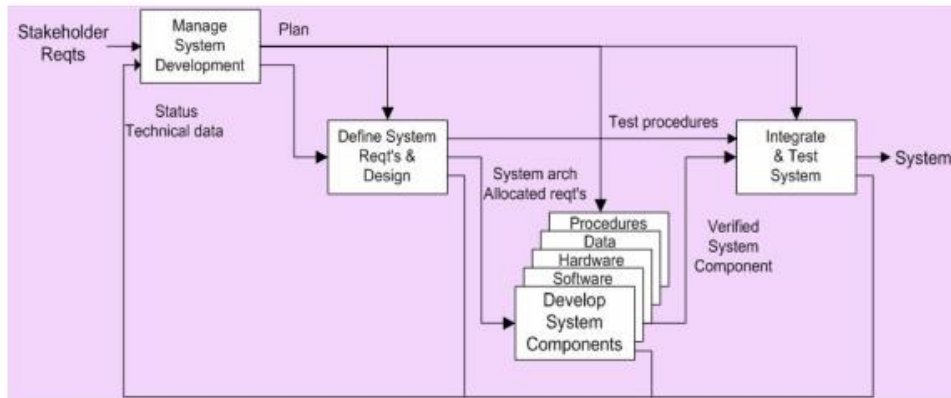


Figure 16: OOSEM Activities for the System Development Process. (Adapted from [92]).

4.6.8. System Modeling Tools

MBSE applies the concepts of OOSEM, the Unified Modeling Language (UML), which is the primary and most widely accepted standard for Object Oriented (OO) modeling and analysis, and the SysML Profile of UML which it is the root language standard on which SysML builds and adapts the basic language to the needs of SE [94, 96, 102]. The UML and SysML language standards are maintained by the Object Management Group, which publishes a family of related standards and other documents. SysML⁸ is a general-purpose graphical language for modeling systems that may include hardware and equipment, software, data, people, facilities, and other elements within the physical environment. This language supports modeling requirements, structure, behavior, and parametrics to comprehensively describe a system, its components, and its environment. The language includes nine diagram kinds, each with many features. The semantics of the language enable a modeler to develop an integrated model of a system, where each kind of diagram can present a different view of the system being modeled. The model

⁸ OMG Systems Modeling Language (OMG SysML™) is the official name of the language, but it is referred to as SysML for short. Additional information on SysML can be found at the official OMG SysML website at <http://www.omgsysml.org>

elements on one diagram can be related to model elements on other diagrams. The diagrams capture the information in a model repository and allow visualization of the information from the repository to help specify, design, analyze, and verify systems. SysML has significant benefits in modeling physical design because of its powerful representation of structures and their relationships. UML-2 is a rich and complex modeling language, and SysML further enhances its architect's ability to deal with requirements, performance, design, integration, and other SE processes and tasks. The explicit intent of SysML is to provide better tools for applying Object Orientation principles to the problems faced by system developers and, more broadly, by planners of complex social systems. For this purpose, SysML is suitable to support the system specification, analysis, design, verification, and validation, which include data processing, capacity procedures, and all related elements. For better understanding, SysML is a UML-2 Profile and reuses a subset of the basic UML modeling elements, represented by UML4SysML in Figure 17, which is the standard portrayal of their relationship [96].

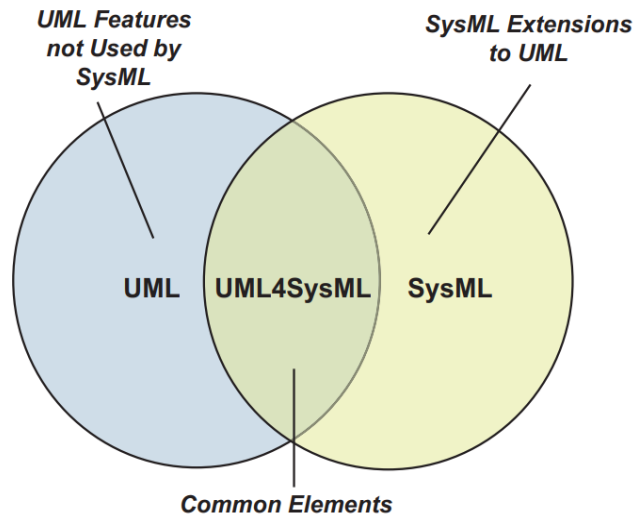


Figure 17: Relationship of SysML to UML (Adapted from [96])

It is worth noting that SysML and UML are not software or methodologies but visual modeling languages. Therefore, MBSE integrates them into the methodology, facilitating lifecycle development activities and unambiguous communication, and SysML provides a graphical representation to support SE design and analysis.

4.6.9. SysML Modelling Approaches

As defined in Section 5.4 of this Chapter, SysML is a general-purpose graphical modeling language that supports complex systems' analysis, specification, design, verification, and validation. These systems can include many things, such as complex social settings like human settlements. As clearly stated earlier, the language is intended to facilitate the specification and architecture of systems and specify components that can be designed using other domain-specific languages. In addition, it is useful in facilitating the application of MBSE approach to create a cohesive and coherent system model that delivers benefits, as described in Chapters 2 and 3. Finally, SysML can represent aspects of systems such as structural composition, interconnection and classification, flow-based behavior, messages, and states, constraints on physical and performance properties, allocations between behavior, structure, and constraints, and relationships between requirements and other system elements, and enables testing.

4.6.10. SysML Diagram Overview

The SysML environment includes nine diagrams, as shown in the taxonomy (Figure 18), which summarizes each diagram type and its relationship to UML diagrams. There are:

- (i) Package Diagram (Pk) presents the organization of a model in terms of packages containing model elements (identical to the UML package diagram).
- (ii) Requirements Diagram (Req) specifies the requirements to satisfy and their relationships with other design elements to support requirements traceability (not in UML).

- (iii) Activity Diagram (Act) shows flow-based behavior, indicating the order in which actions execute according to their inputs, outputs, and controls and how actions transform inputs into outputs (modified from UML Activity Diagram).
- (iv) Sequence Diagram (Sq) exposes the behavior of messages exchanged between subsystems or other system elements (identical to the UML Sequence Diagram).
- (v) State Machine Diagram (Stm) represents the behavior in terms of transition between states triggered by events (identical to the UML State Machine Diagram).
- (vi) Use Case Diagram (Uc) presents functionality in terms of the use of a system by external entities to achieve a set of objectives (identical to the UML Use Case Diagram).
- (vii) Block Definition Diagram (BDD) presents the structural elements, called blocks, as well as their composition and classification (modified from the UML class diagram).
- (viii) Internal Block Diagram (IBD) shows the interconnections and interfaces between the parts of a block (modification of the UML composite structure diagram).
- (ix) Parametric Diagram (Par), precises constraints on property values and combinations of equations to perform the required computations (not in UML).

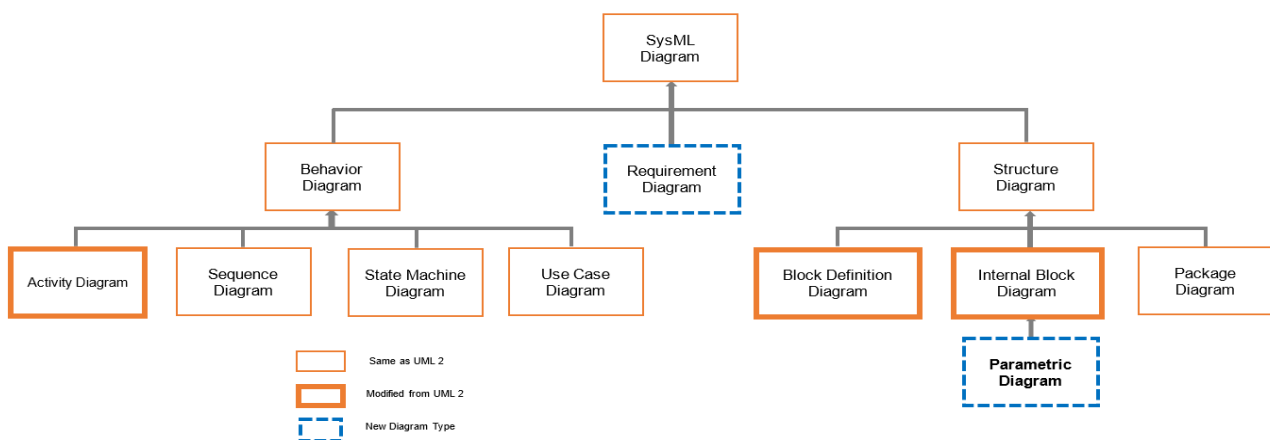


Figure 18: SysML Diagram Taxonomy and SysML-UML Relationship (Adapted from [96])

4.6.11. Development of the Initial Integrated Human Settlement System

This research adopts MBSE methodology as being capable of realizing a systematic view for an integrative conceptualization of a typical human settlement system from an operational data processing perspective. To this end, the SE approach is used to design an initial model of the Integrated Human Settlement System in the form of a system and a Triple Nexus Framework for water, energy and housing in a humanitarian context.

To model the system, this research adopts No Magic Cameo Systems Modeler Enterprise Edition, which is the most suitable software for modeling complex systems and offers a leading cross-platform collaborative MBSE environment that provides robust, intelligent and intuitive tools for verifying requirements, tracking progress, defining and visualizing all aspects of the system. The model's holistic structure for the integrated human settlements system and triple Nexus framework is illustrated in Figures 19 and 20 below. Figure 19 shows the overall structure of the model with the six required subsystems previously validated during the group interviews. The six subsystems designed by the block network are all interdependent and converge their processed data into an integrated data platform or database. The structure shows that all subsystems are linked by a standard platform that integrates them and makes them work together as connected parts of the human settlement system. It shows the subsystems as parts of the human settlement system in which data blocks draw on data produced by different sources in different subsystems and process them into useful, standards-compliant data.

From a functional and interpretative point of view, data processing takes place in three main stages. In the first stage, data is collected from various sources, including during the needs assessment cycle, and then transferred to the various subsystems. The data collected is verified by experts in each sector, and then stored on the individual data platform. In a second step, the data

produced after the verification process is processed at this level by prioritization and integration procedures from an integrated composite data perspective, to produce a meaningful integrated composite data set useful for multi-sector programming. Data processing at the data block level produces "operationally meaningful" quality data for use and "operationally meaningful composite data" for multi-sector programming. In the final stage, the processing of the different data types will produce corresponding information products at the information block level, linked to the subsystems for automatic updates as required. At the platform level, the (optional) data and information produced are made available to consumers.

For this research, the integrated human settlement model is designed to present the six required subsystems and their respective components, in line with the concept definition (see section 4.2) and based on the architecture presented in section 4.3. The six subsystems are as follows: Urban planning and infrastructure; Institutional and governance; Social services; Economy and finance; Ecology and environment; Populations, represented respectively by "subsystem" blocks of the system, which is represented by the "system" block. The components of the subsystems are represented in the rights of each subsystem by "component blocks". They are directly linked to each subsystem by a "Directed composition" association link (composition with navigability arrow). The "Directed composition" link (composition with navigability arrow) presents the part or blocks and uniquely belongs to the higher-level block.

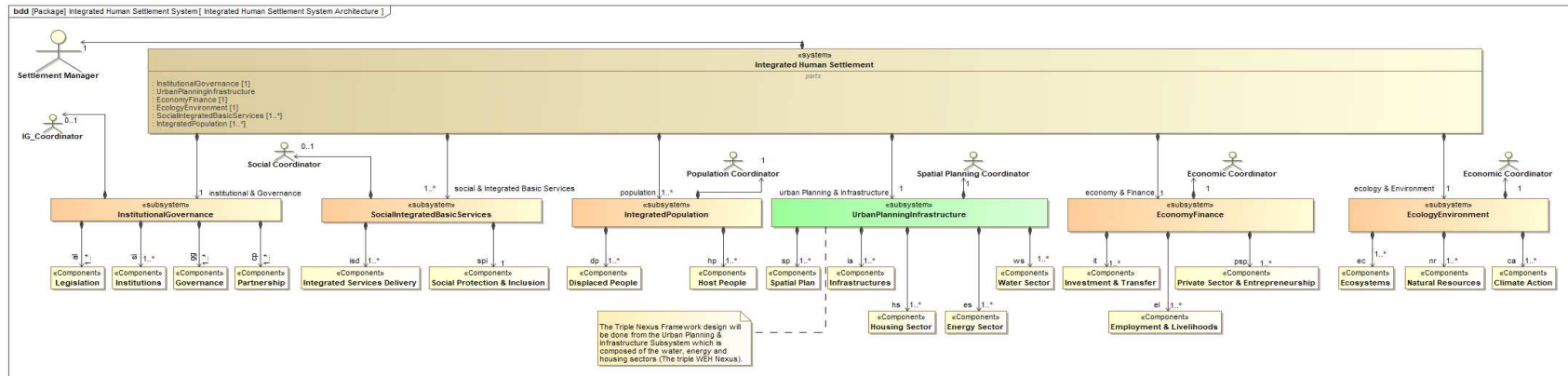


Figure 19: Simplified SysML Integrated Human Settlement System Structure

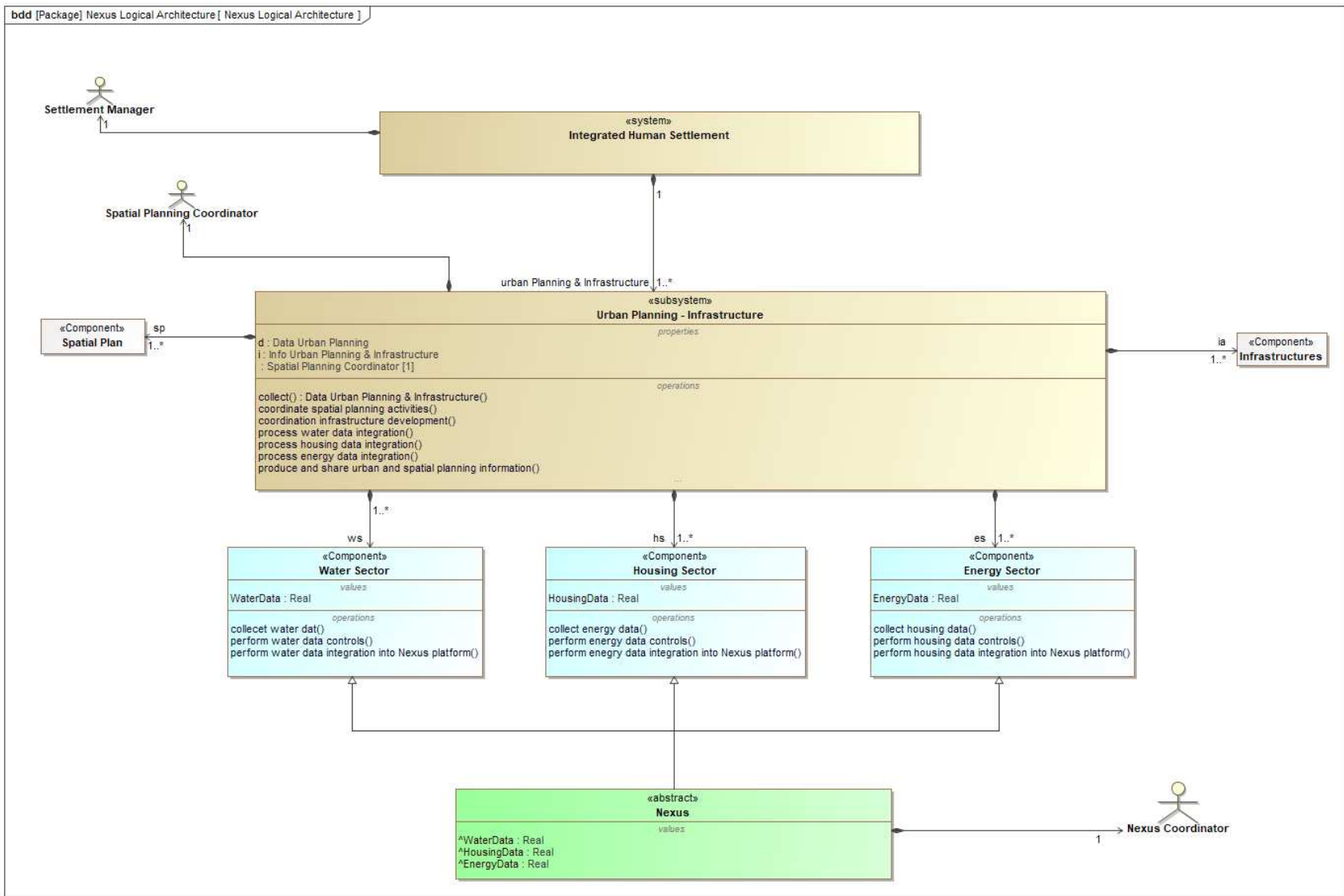


Figure 20: Simplified SysML Triple Nexus System Structure

As detailed in Figure 19, components having composite association links with subsystems establish direct relationships with them with specific roles in the data production process and should be understood as follows:

- (i) Urban Planning & Infrastructure subsystem consists of 5 components (spatial plan, infrastructure, water sector, energy sector, housing sector).
- (ii) Institutional subsystem consists of 4 components (legislation, institutions, governance, and partnership).
- (iii) Social & Services subsystem has 2 components (social and services delivery).
- (iv) Economy comprises 3 components (investment, employment, and entrepreneurship).
- (v) Environment comprises 3 components (ecosystems, climate, and natural resources).
- (vi) Populations subsystem has 2 components (displaced people and host people).

Urban Planning is the subsystem from which the Triple Nexus is derived, due to its components that contain the three relevant sectors of water, energy, and housing. The designed system model (Figure 21) presents the integrated data platform that receives all data from the components and subsystems, storing them in a secure and accessible database. All data is generated and processed at the subsystem level, as illustrated in Figure 20. The resulting data and information are then stored at the integrated data and information platform level, where they are consumed or shared within the humanitarian community according to agreed protocols. The integrated data platform is designed to focus on processing quality data and sharing across the six integrated subsystems.

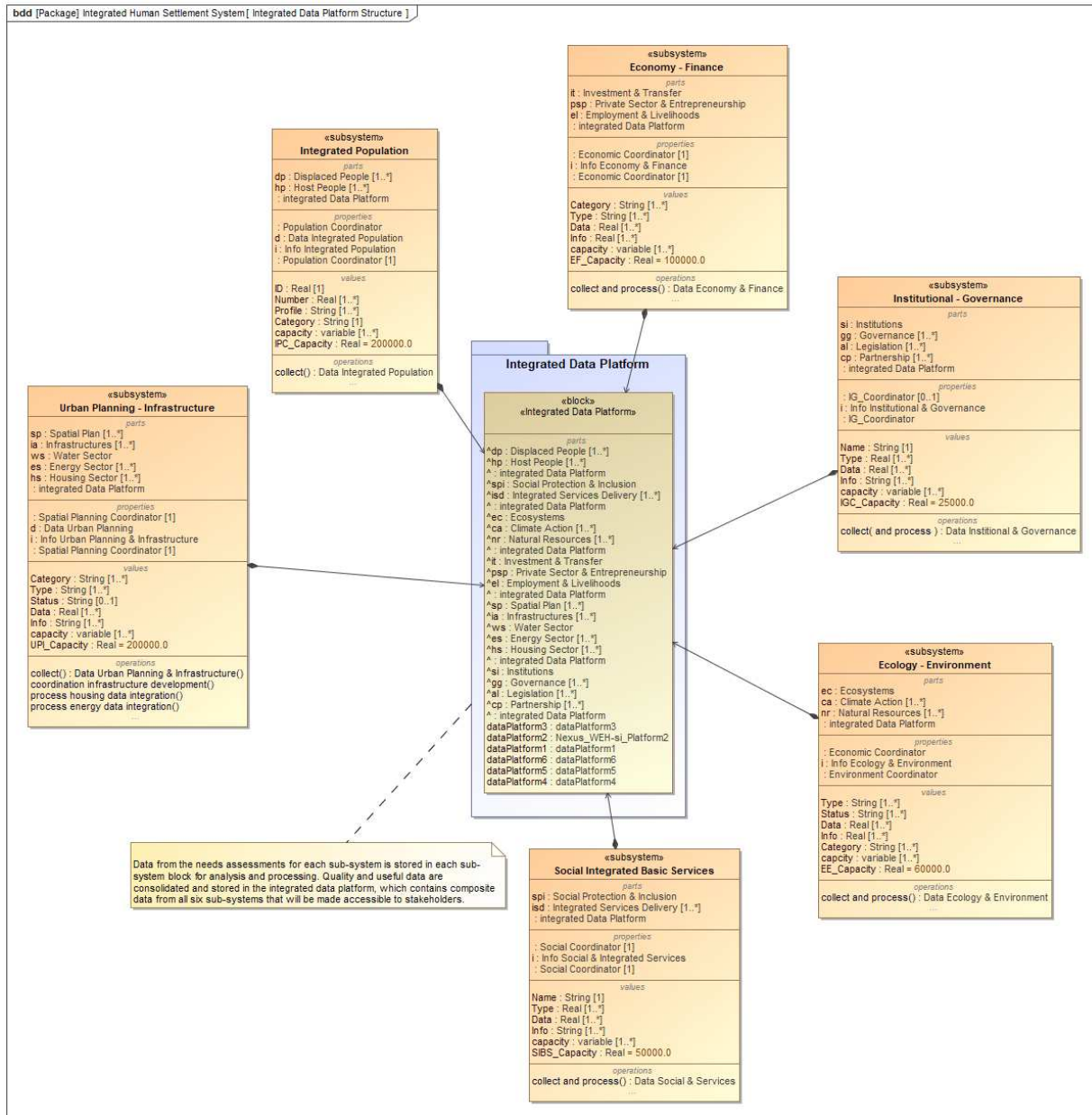


Figure 21: SysML Integrated Data Platform Diagram for a Settlement System

4.7. Chapter Summary

In Chapter 4, the concept of Integrated Human Settlement System is defined as a physical, technical and social complex, and this research demonstrates that, to a large extent, the shortcomings identified in current approaches can be addressed significantly and effectively through an integrated system model as it can streamline data processing across the entire system.

This Chapter demonstrates that, in order to address the complexities of human settlements in the face of the current approach that produces disconnected systems, where subsystems are neither interconnected nor integrated, the solution proposed by the enhanced model-driven systems approach is responsive in the sense that it operates as a system.

Furthermore, SE approach is described as a potential means to process operational megadata in complex socio-technical systems while keeping its related elements interdependent as a whole and well-integrated.

In Chapter 4, I explicitly introduced the SE approach, MBSE methodology, and SysML, described as interdisciplinary approaches that aim to solve complex stakeholder problems and identify requirements used to design systems, deal with complexities, and test them to ensure their successful performance. The SE approach and MBSE methodology are used to represent an initial concept of the Integrated Human Settlement System and will be used in more detail in the following Chapter 5 to model the system and subsystems, including the design of corresponding key diagrams, followed by the necessary optimization analyses.

CHAPTER FIVE: INTEGRATED HUMAN SETTLEMENT SYSTEM MODELING

5.1. Introduction

Chapter 4 focused on MBSE as a means of conceptualizing an Integrated Human Settlement System. Chapter 5 goes further and develops model-based solutions that would address the challenges identified in the previous chapters that hinder the achievement of sustainability in human settlements. In detail, this Chapter addresses the critical issues related to improving the living conditions of displaced populations through the design of an integrated settlement model using MBSE and SysML which are considered as innovative methodologies in the context of humanitarian efforts, relatively unexplored to date.

The literature review showed significant advances in building the Nexus approach, which still present major challenges in streamlining data processing across sectors. For example, in the water, energy, and housing sectors, where compliance with standards continues to pose challenges, as revealed by the results of surveys conducted in refugee settlements in Kenya in October 2023.

To contribute to addressing these challenges and providing practical solutions that would improve the smooth and harmonious functioning of human settlements, this research builds on the advantages of an integrated human settlement concept, which appears to be one of the most suitable solutions to the challenges facing contemporary humanitarian settlements. In Chapter 5, I present a comprehensive analysis of human settlement sustainability, and propose a new methodology, with important theoretical and practical implications, that draws on MBSE and SysML approaches to develop an integrated human settlement system model. The model is designed in a way that the six subsystems and their components function together, focusing on the processing of operational data generated by the system. To ensure a smooth functioning, two scenarios are presented to

assess the system's capacity to efficiently generate and process data. The data processing modeling the triple nexus framework is derived from the Urban Planning subsystem.

Chapter 5 demonstrates the effectiveness of the methodology for modeling the system that efficiently and coherently maintains the properties of its subsystems and components. Finally, the proposed human settlement system is tested to illustrate how it would respond under a range of sustainability conditions in a real-world context.

5.2. Integrated Human Settlement System Model

5.2.1. Methods, Tools, and Process.

In terms of methods and tools, I used the MBSE methodology for the system design phase and performed a simulation to test its performance. MBSE is a potential and robust methodology for modeling complex systems such as human settlements while SysML is a tool that facilitates the MBSE process, ensuring the automation and analysis of the built system. For this research, MBSE is the most appropriate option to model the system in order to generate and process data from the subsystems, while providing insights for effective decision-making. Based on this, MBSE methodology is complemented by SysML as a tool and standardized language that has the advantage of being unambiguous, ensuring consistency, preventing attempts, improving the accuracy and efficiency of communication, being scalable, better managing complexity and, detecting errors or omissions at an early stage of system development. Figure 18 illustrates the taxonomy diagram that establishes the intended links between SysML diagrams. In terms of software, Cameo Systems Modeler is used as a cross-platform collaborative MBSE of Magic Draw that enables defining, visualizing, and tracking the steps, aspects and processes of system design. It facilitates the visualization of all aspects of the system in a standard way and is compliant with

SysML diagrams. The diagrams included in SysML are used to specify the structure and behavior of the system.

To illustrate the operability of the system, the tool is used to clearly define its structure and logical architecture, as well as the links between all subsystems and components. Finally, the system is executed under specific conditions for analysis purposes.

The human settlement system modeling process is achieved with the design of diagrams that present the necessary levels of detail to justify the interconnections between all subsystems on the one hand, and their components on the other hand. Figure 22 illustrates this process and shows the types of SysML diagrams that I created. It should be noted that this process allows the creation of diagrams expressly required for this research.

ihs: integrated human settlement

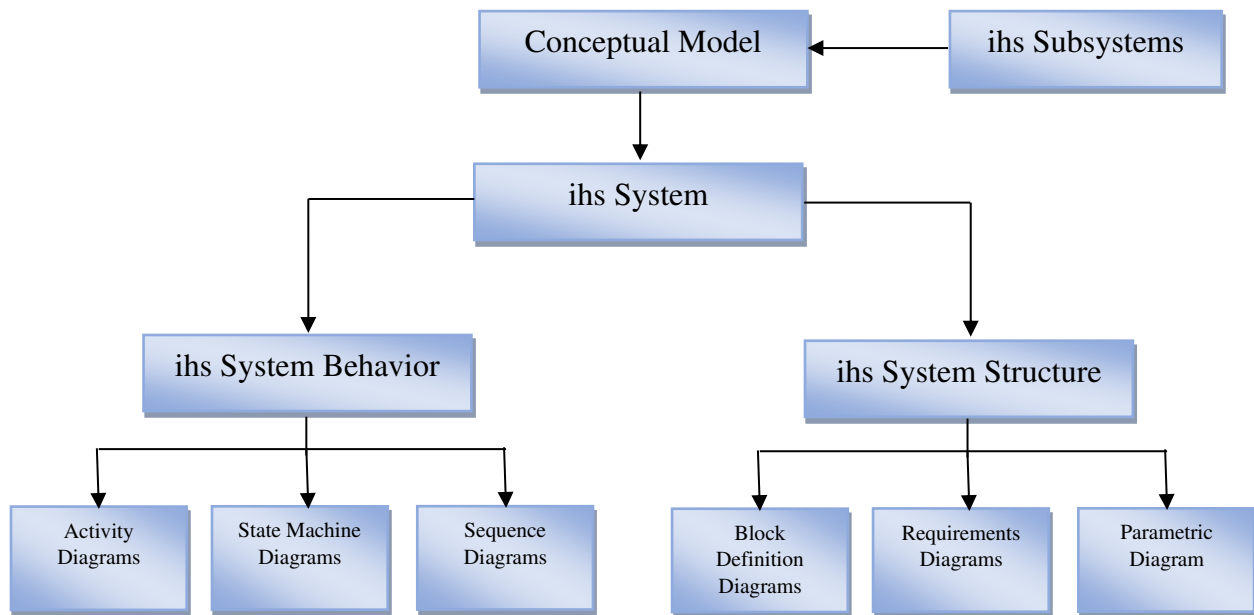


Figure 22: : System Model Development Conceptual Model

5.2.2. Logical Architecture of Human Settlement System

This Section presents the logical architecture in the form of a structural diagram of the Integrated Human Settlement System with the six subsystems illustrated in Figure 23. The logical architecture is defined in a SysML Block Definition Diagram (bdd). The components of each subsystem are also defined in a SysML Block Definition Diagram (bdd) and are interdependent with the subsystems on which they depend respectively.

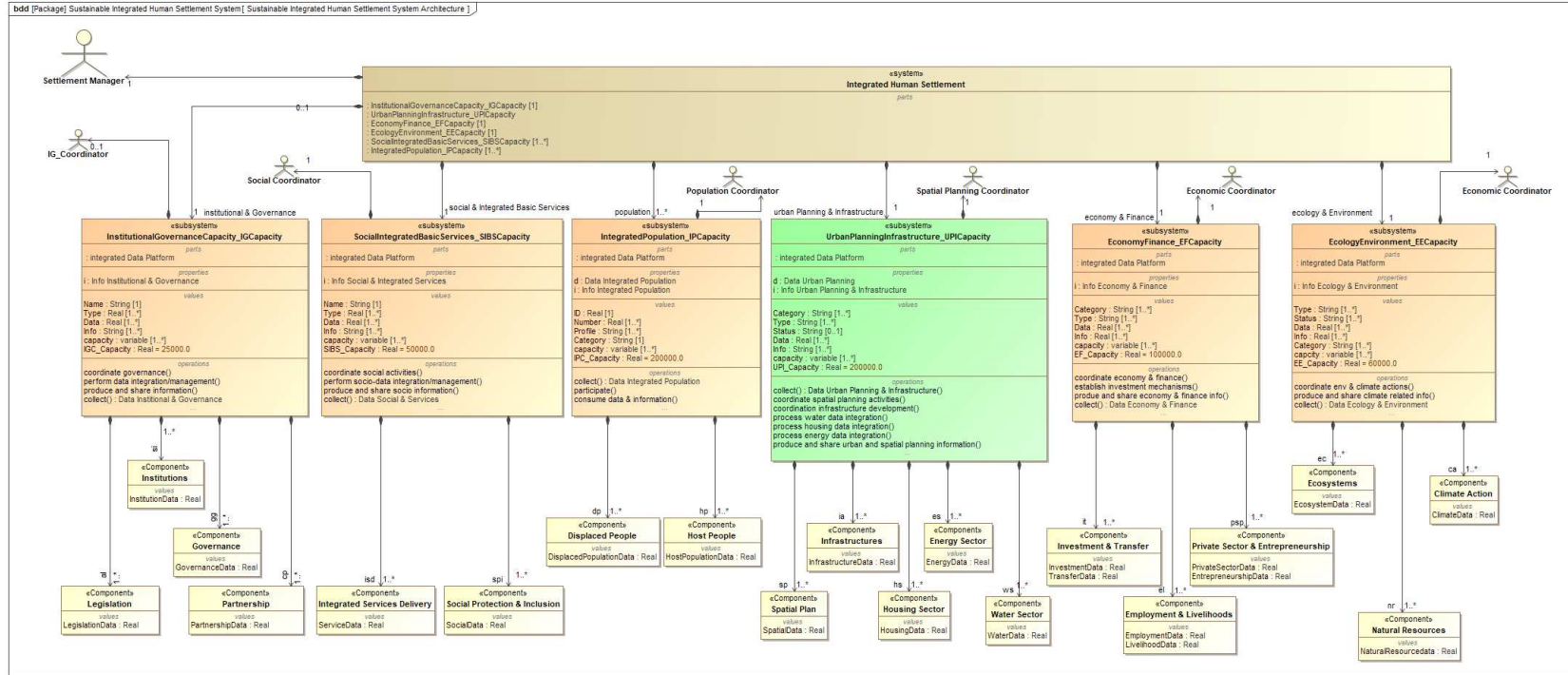


Figure 23: SysML BDD Diagram showing a Logical Architecture of the Integrated Human Settlement System

5.2.3. Stakeholders Participation

The application of SE emphasizes the definition of stakeholders, because the expression of needs and the way the system designed should emanate from the outset, to serve as a basis for the system design process. Therefore, SE allows for a multidisciplinary approach to transform a set of requirements into a balanced system solution that meets the stakeholder se needs [101, 102].

Before developing the system, a stakeholder analysis is carried out through large-scale consultations, resulting in the selection of key stakeholders with a particular interest or whose involvement could influence the life cycle of the system. Typically, needs are expressed by the system stakeholders, and meeting these needs is a crucial step that validates the performance of the system. System stakeholder analysis is a crucial process in the SE methodology, which identifies and assesses the needs, expectations and interests of people and organizations that influence or are affected by the system. For this human settlement system, key stakeholders are pre-selected as shown in the diagram presented in Figure 24. Some observers argue that the composition of stakeholders may vary in humanitarian contexts, depending on the immigration laws and policies in force in the country. For this research, a literature review documented practices in several operations such as Kenya, Ethiopia, Mali, Democratic Republic of Congo, and Greece, with the aim of achieving some degree of harmonization. The result is the diagram presented in Figure 24, which indicates the system stakeholders. To satisfy this methodological requirement, I compiled a list of key stakeholders involved in or responsible in one way or another for the planning and management of the human settlement system.

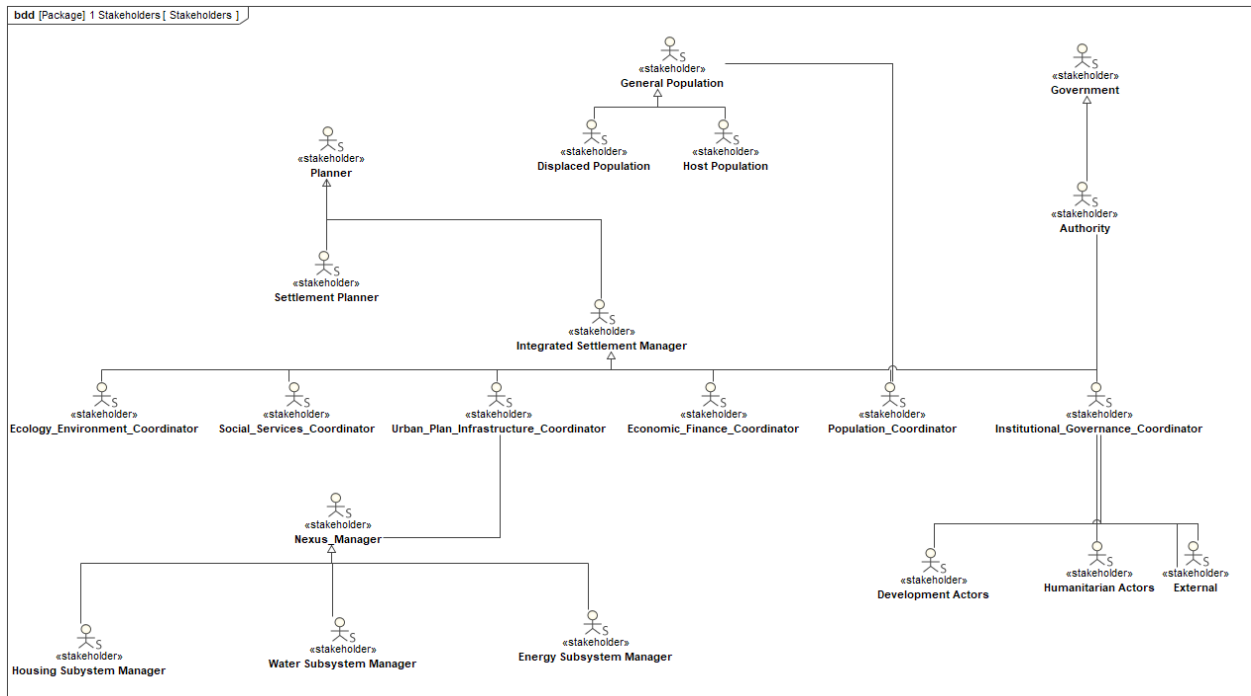


Figure 24: SysML BDD Diagram showing System's Stakeholders Composition

5.2.4. System Requirements

The SE process includes activities that establish the objectives that the system must support, specify system requirements, synthesize alternative designs, evaluate alternatives, assign requirements, and verify that requirements are met [96]. After identifying the stakeholders in Section 5.2.3, this work defines and develops the system functional requirements diagram, which is presented in Figure 25. The system requirements are specified in terms of stakeholder needs and associated effectiveness measures. The system requirements diagram is part of the SysML behavioral diagrams and its main purpose is to record all relevant stakeholders and their requirements, capture the hierarchies and relationships that must be satisfied during the system operability verification and validation such as derivation, verification, satisfaction, and refinement.

For the construction of the system requirements diagram, the logic is guided by a certain order that first begins with the identification of system requirements as illustrated in Figure 25. A State Machine Diagram is created to present the system behavior to satisfy these requirements, followed by the analyses and simulation tests. Block Definition Diagrams (BDD) are then created based on the information contained in the State Machine Diagram and Activity Diagrams. Parametric Diagrams are then generated from the Block Definition Diagrams as shown in the following Sections. Figure 25 presents the initial development of the Integrated Human Settlement System requirements. It shows each requirement with an identifier ("id") and descriptive text ("txt") to facilitate traceability. The diagram is broken down into a set of sub-requirements that illustrate further relationships, such as refine, satisfy, and derive to support traceability. Requirements identification is a fundamental factor for the successful development of a system [96]. Ultimately, the resulting system requirements diagram illustrates the conditions to be satisfied and the functions to be performed and achieved, and contains requirements for functional objectives, safety objectives, usage objectives and usability objectives.

5.2.5. State Machine High-level Behavioral Diagram

A SysML State Machine (STM) diagram is created to perform the system behavior analysis, as illustrated in Figure 26. The STM diagram specifies the system states, which are presented as a sequence of actions and events that the settlement system undergoes, from the creation of the system's data platform to the sharing of data throughout its lifetime, without deviating from the requirements. The preliminary stages involving the collection of data at subsystem level their inputs into the platform are outside the scope of this research. However, the processes involved in processing, analyzing and simulating data are illustrated by other behavioral diagrams presented in the following sections. Figure 26 shows the STM diagram, which defines how system states change when transitions are triggered. The diagram represents system behavior in terms of event-driven transitions between states. For example, the system can reject or approve a request for access to the data platform when the user does not meet the prerequisites. In addition, the system can guide the user to the category of data he is looking for, which is done by entering a certain access code provided by the Settlement Manager. The resulting data is stored at the data platform level, derived from the six subsystems integrated by the data integration process, where it can be accessed and retrieved by stakeholders or users.

The STM diagram illustrates the user's decision and the behavior of the data platform in the states it passes through when subjected to user activity. It also highlights the high-level states on which the main functions focus, conditions for secure access to the platform, and access to the various nexus data categories that generally comply with system requirements.

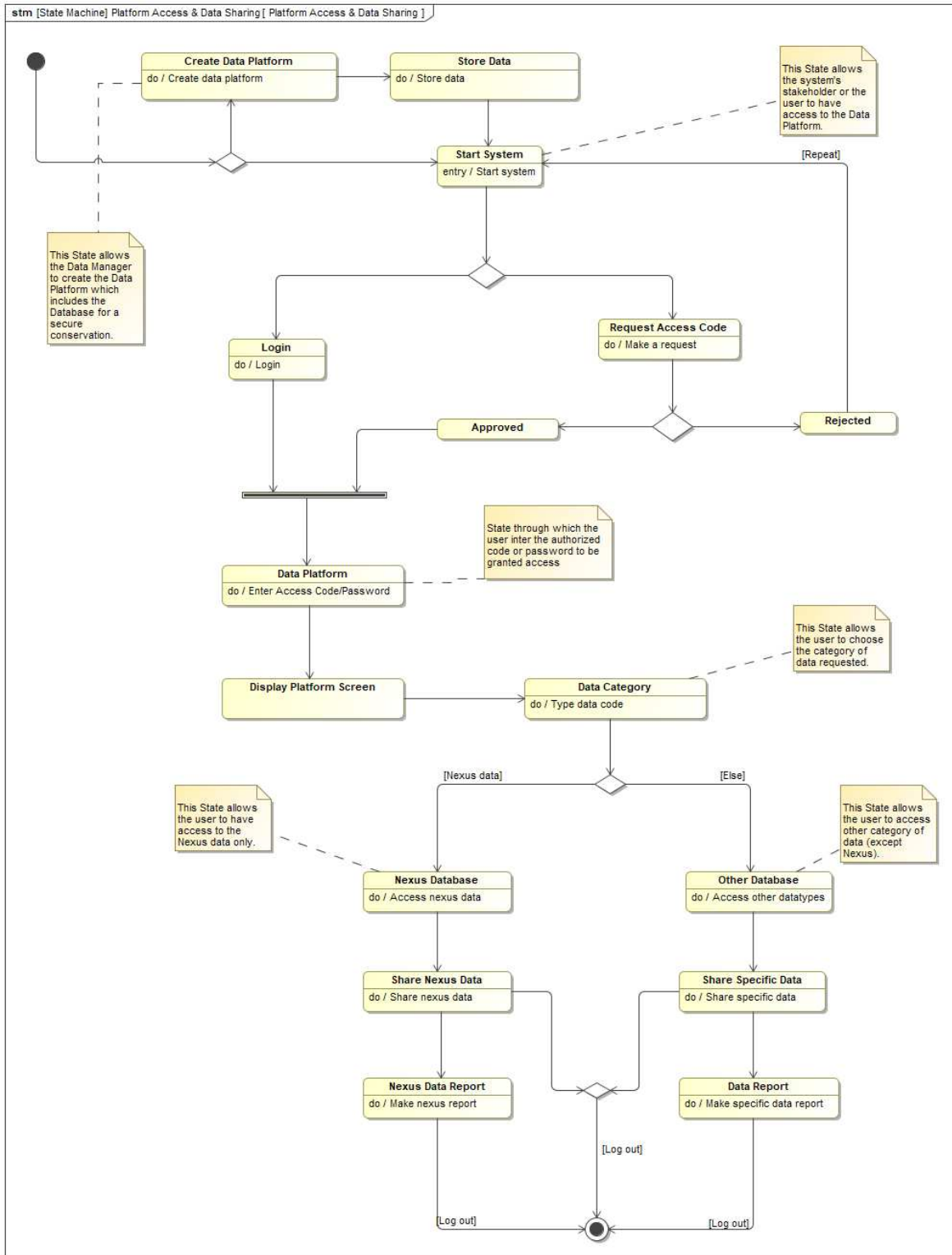


Figure 26: SysML High-level State Machine Diagram

5.2.6. System Data Processing Operations

This Section presents the steps involved in creating the SysML diagrams needed to complete the data integration process and the integrated data platform. The MBSE approach has proven to be very well suited to address the complexity of the human settlement and carrying out the transformation in an integrative way without fragmenting the system. A holistic and integrative conceptualization of the human settlement system is therefore presented from a systematic perspective. The perspective of data processing and sharing is highlighted, and an integrated, standardized data platform has been conceptualized.

The structure is illustrated in Figure 27, which shows all the subsystems and their respective components connected to the integrated platform.

From a process point of view, the platform's operations are illustrated iteratively and progressively in Figures 27, 28, 29, and 30. Figure 27 illustrates the six subsystems and their components as part of the system in which data blocks process data from the sources. Each subsystem receives data from its component, which in turn generates data from the sources. The data is then transferred to the six singular platforms at the subsystem level. Data verification, prioritization and processing are performed at the singular platform level to ensure data quality before transfer to the integrated data platform, as illustrated in Figures 28 and 29 respectively. Figure 30 illustrates the integrated data platform model, with data from the various subsystems processed to make it available and accessible to stakeholders via the integrated data platform for planning and managing human settlements.

Figure 28 illustrates the process of transforming into information or information products consumed by stakeholders. Each platform generates data, processes it to produce composite data, and transfers it to the integrated data platform or information block. The data processing operation

is illustrated in the STM diagram in Figure 31. This STM diagram illustrates the states through which the integrated human settlement system passes as it processes operational data through its six sub-systems until it is transferred to the integrated data and information platforms relevant to consumers. Data sources are the starting point for data production via the means commonly used by needs-based data collection teams, such as tablets or smartphones. The data will then be obtained and stored at the data block level presented as a data platform, and it is at this level that the data will be processed and stored by the integrated platform. This process can be broken down into four main steps:

(i) Operational data is collected from external sources via the components of the six subsystems and stored on the various data platforms (Figure 27).

(ii) Data is then verified, prioritized and consolidated at the level of each platform, before being transferred (quality and composite data) to the integrated data platform to be made available to consumers or stakeholders (Figures 28 and 29).

(iii) The integration processing operation is based on states passing through each data subsystem, before transferring them to the integrated data and consumer-relevant information platforms (Figure 28).

(iv) Data extraction processing is carried out to extract the meaningful information products stored at the information block level (Figure 30).

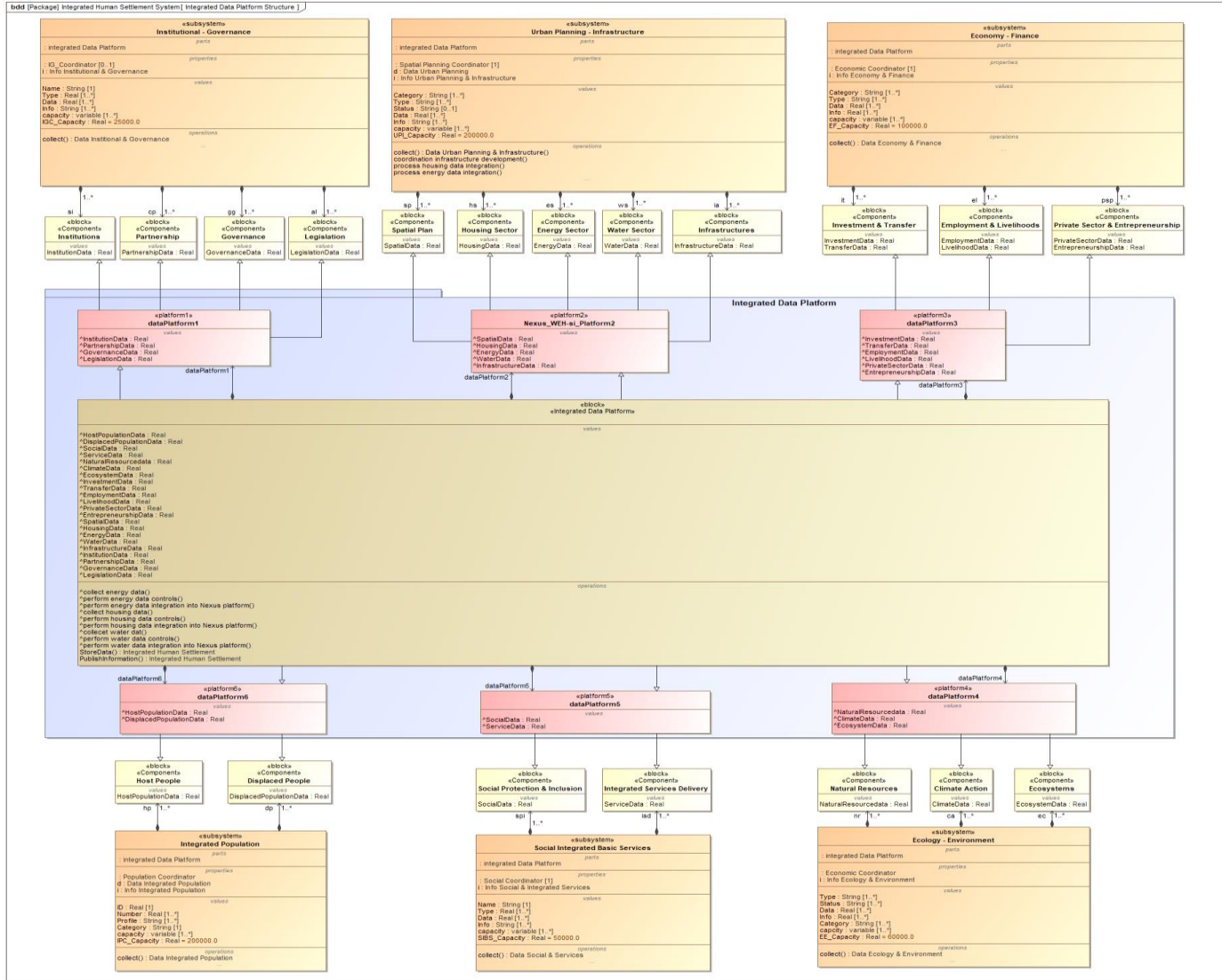


Figure 27: SysML Integrated Settlement System Diagram showing the Data Integration Processing

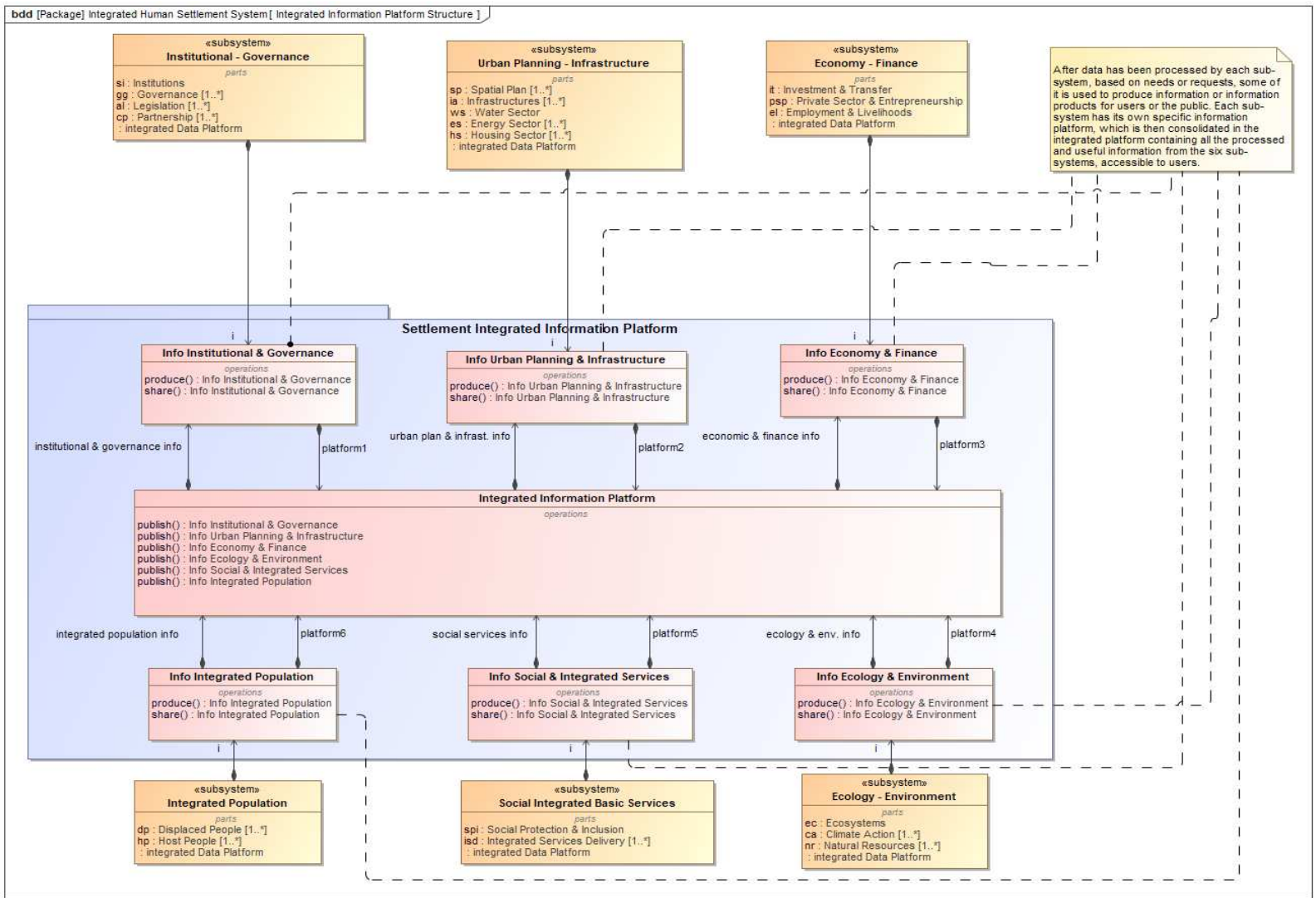


Figure 28: SysML Integrated Settlement System Diagram showing the Information Processing

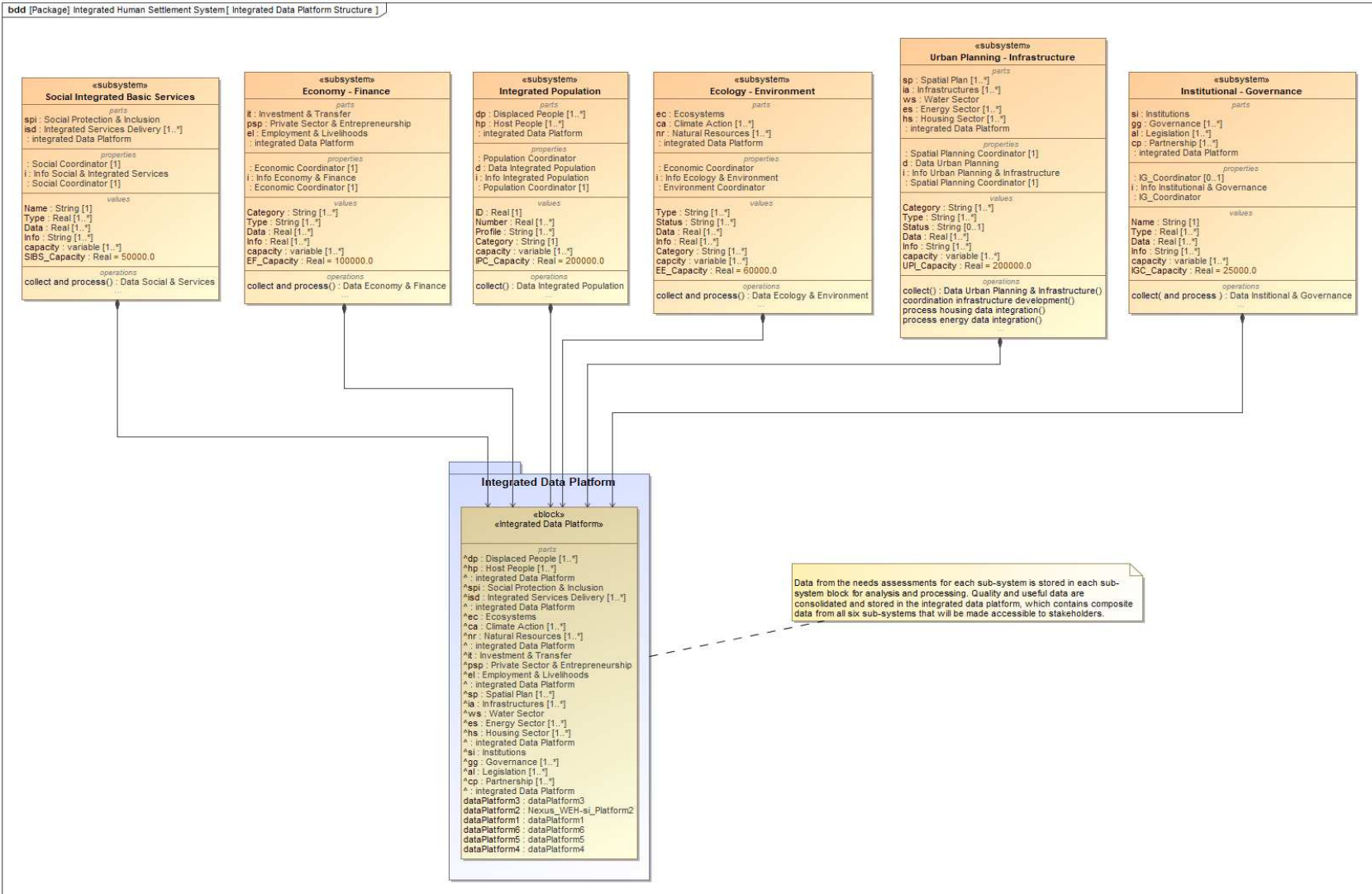


Figure 29: SysML Integrated Settlement System Diagram showing the Integrated Data Platform

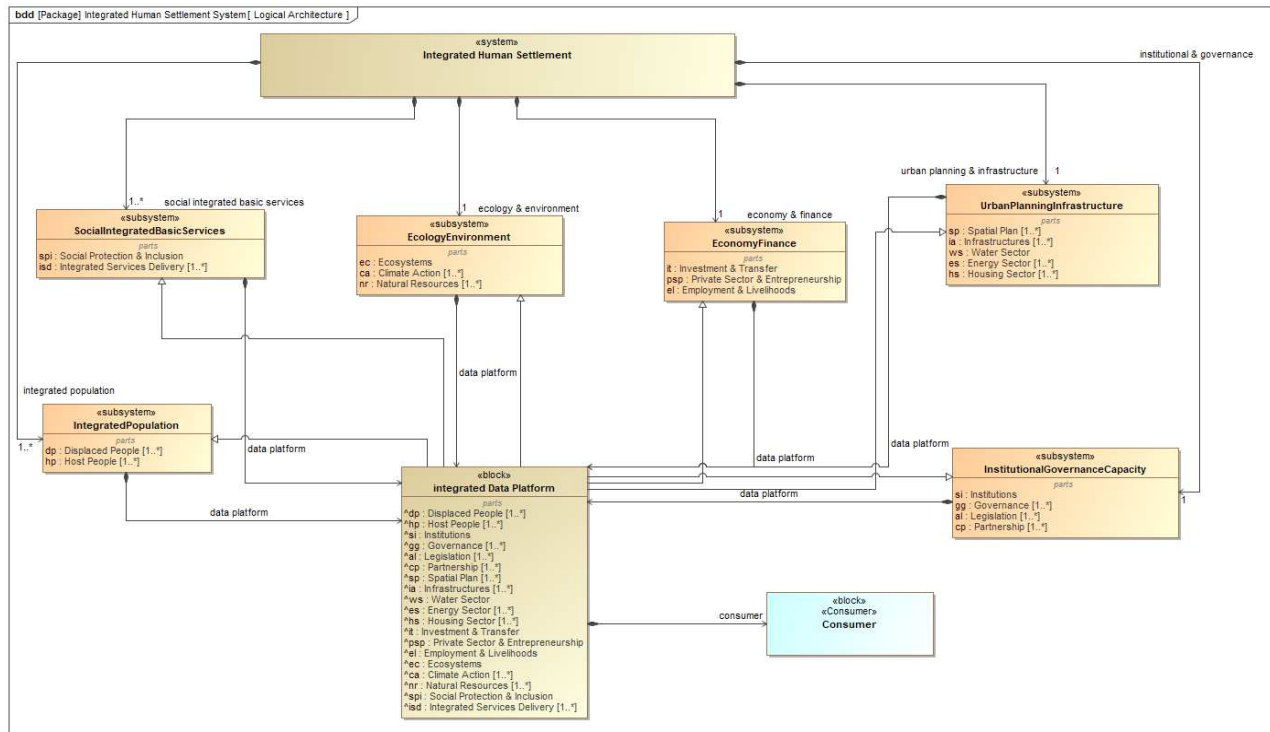


Figure 30: SysML Integrated Human Settlement System Diagram showing the Integrated Data Platform

Data processing is illustrated in the STM diagram shown in Figure 31. This diagram presents how the integrated human settlement system processes data through the six subsystems until it is transferred to the integrated data and information platforms relevant to consumers (Figure 30). Data sources are the starting point for data production through the means commonly used by needs-based data collection teams, such as tablets or smartphones. The data will then be compiled, disaggregated and stored at the data block level. At this level, the data is processed and stored in the integrated platform.

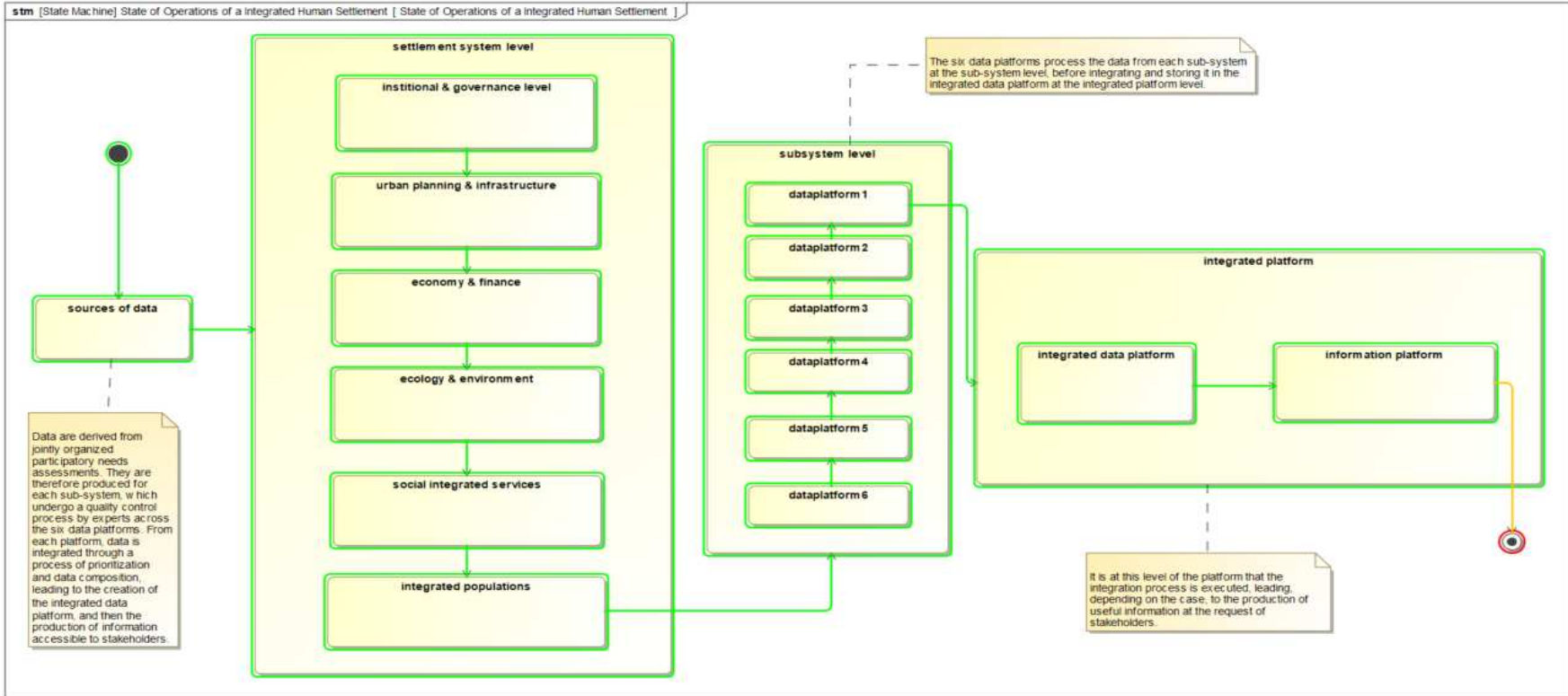


Figure 31: SysML State Machine (STM) Diagram showing Model Operations

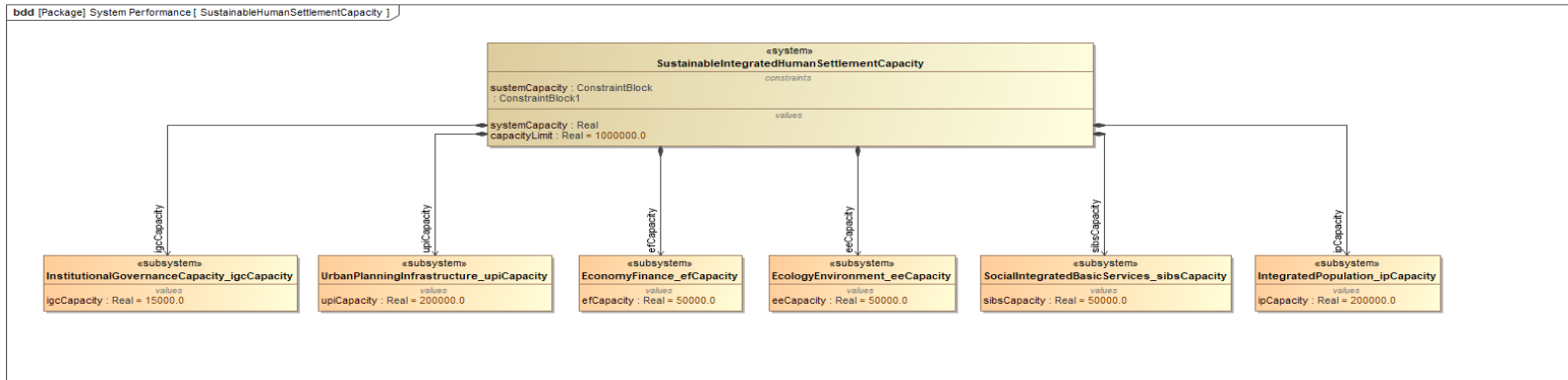


Figure 32: SysML Block Definition Diagram of System Capacity Analysis Representation

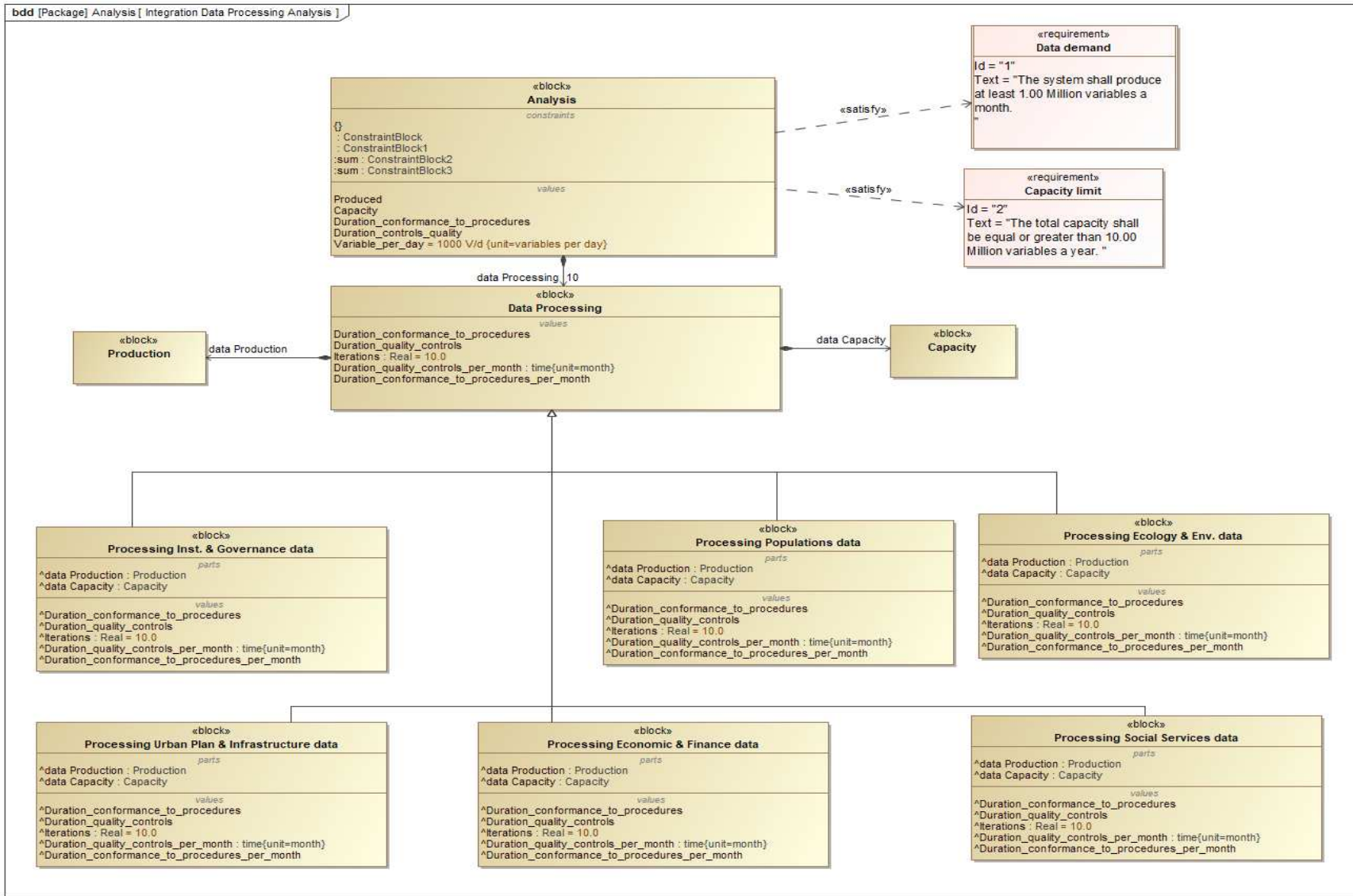


Figure 33: SysML Block Definition Diagram of Capacity Analysis showing the System Requirements

5.3. Integrated Human Settlement System Capacity Analysis

The system is subjected to two scenarios to determine its capacity to effectively satisfy the requirements. Figure 33 presents a Block Definition Diagram of the system with the two requirements to be met being: (1) the system shall produce at least 1.00 million variables per month; and (2) the total capacity shall be equal or greater than 10.00 million variables per year.

Both scenarios are illustrated in the Parametric Diagrams of Figure 51 and Figure 52 (Appendix B). The scenarios test the system's behavior when subjected to capacity constraints to provide a certain level of capacity and data delivery as a real-time constraint. Both types of constraints are adopted in order to analyze the functionality and reactions of the system when subjected to these two conditions.

The Activity Diagrams (Figures 47, 48, 49, 50 in Appendix A) are embedded in the composition system behavior, which is captured in the State Machine Diagram in Figure 31. As shown in the diagrams, the Activity Diagram describes what each of the six subsystems does to operate the system's functions to satisfy its requirements. So, when an activity is initiated, execution begins at the initial node, then moves to the next activity until reaching the final activity and, later, the final node. For the system, as presented in Figure 44 and Figure 45 (Appendix A), a set of actions are performed in each state in the form of activities, which are executed in Activity Diagrams before the system can move to the next state.

The SysML Parametric Diagrams shown in Figure 51 and 52 (see Appendix B) present constraints as refinement actions of system requirements. These constraint blocks are presented as equations expressed using parameters. Parametric Diagrams support the system to perform the necessary computations in certain scenarios illustrated by a systems of equations.

The first scenario is illustrated in Figure 53 (see Appendix C), and demonstrates the system's capacity to continuously process a given amount of data within certain limits imposed on the system. The second scenario is illustrated in Figure 52 and tests the system's capacity to deliver data to stakeholders in real-time. The scenario defines the time to be considered as real-time 't' (in seconds), which is the time required by the system to process operational data: data acquisition (At), data integration (It), data control (Ct), data storage (St), and data sharing (Sht). This time scenario also includes the time required to transfer data to the integrated platform and make it available and accessible to consumers. Figure 54 (Appendix C) presents the corresponding Real-Time (RT) data chart.

5.4. Triple Nexus Framework (TNF)

5.4.1. Background to the Triple Nexus Framework

The importance of the Triple Nexus Framework (TNF) stems from the challenges and problems revealed by surveys conducted in refugee settlements in Kenya in October 2023 and presented in Section 1.2. The surveys revealed that approaches to implementing water, energy and housing services under current conditions do not meet the required standards and do not produce sustainable impacts, mainly due to the decentralization of data processing in the three sectors. The surveys, combined with an extensive literature review, suggests that the Triple Nexus approach, as an integration of the three sectors in the processing and prioritization of operational data, is an optimal and cost-effective solution for achieving sustainable impacts in human settlements. These

findings are also echoed in several other studies widely mentioned in the literature review. In the previous sections, I demonstrated that the three sectors of water, energy and housing, defined as the “Triple Nexus”, process data differently and in parallel. This implies that the same data generated on water, energy and housing are collected from different sources almost simultaneously and in parallel, resulting in redundancy and the creation of three separate databases due to a lack of integration. This would significantly optimize system performance by establishing more rational priorities for planning. This new data processing framework also allows the development of composite data on the three sectors, which has been widely recommended in recent years by most stakeholders to include multi-sector indicators in planning and operations management. Figure 34 shows the SysML Triple Nexus structure developed using MBSE methods.

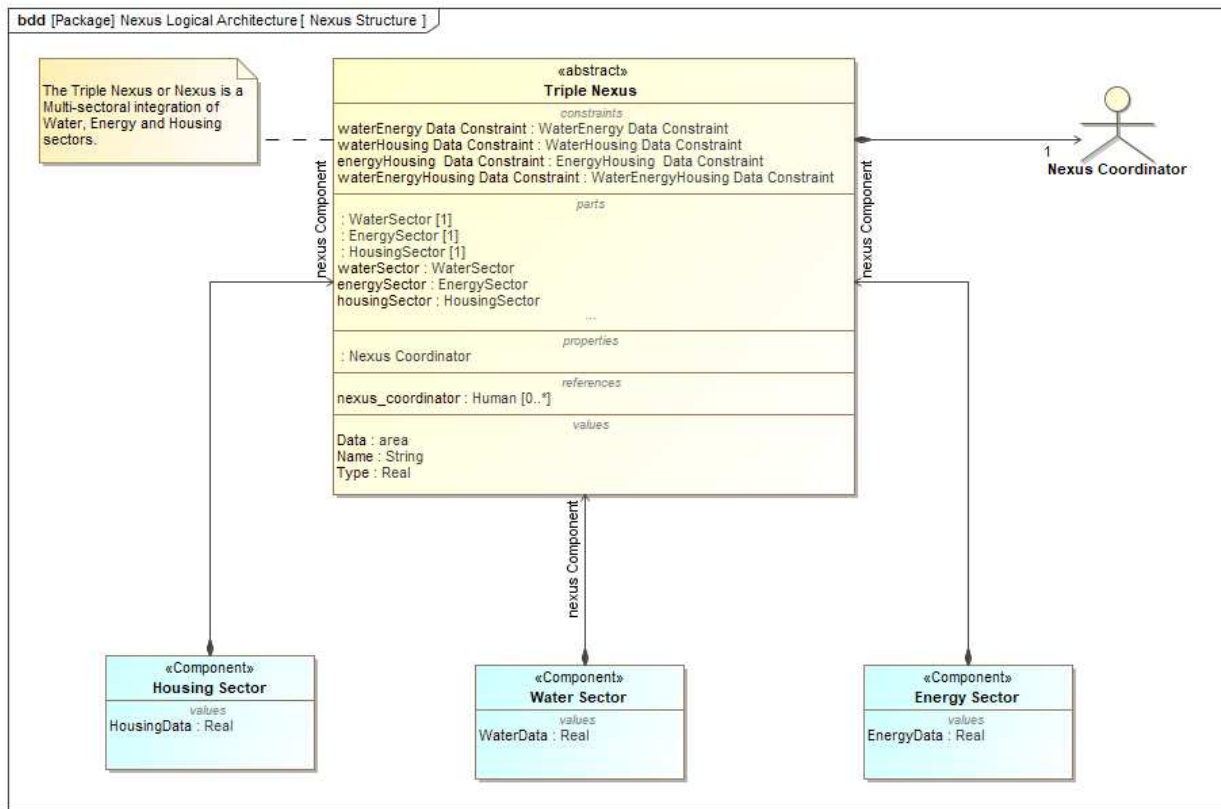


Figure 34: SysML Block Definition Diagram showing the Nexus Framework Structure

This research concludes that the lack of a systemic approach to data management and processing, has often led to poorly designed and unsustainable humanitarian settlements. Systematic data integration is not sufficiently emphasized and, as a result, there is evidence of duplication of efforts in some cases, inefficient and poor quality data management practices [19, 103]. In this research, a cross-impact analysis is conducted which resulted in the design of a novel Triple Nexus Framework that better structures and integrates data across water, energy and housing sectors, providing a more effective and efficient solution to this under-explored area of inefficiencies. The accelerated growth of displaced populations in human settlements and the increased pressure on resources is likely to lead to their depletion, degradation of ecosystem services and irreversible socio-environmental changes in the long term. As discussed in Section 3, the Urban Planning and Infrastructure subsystem is the data source from which the Triple Nexus is derived. The other two components of the subsystem are outside the scope of this research. The Nexus platform is the final step in the Triple Nexus data processing, which is then verified and consolidated before made available to users. At the Nexus level, data relating to the three sectors are processed and recomposed as needed based on planning objectives and expected results.

Following the same methodology, data from the three sectors are collected from external sources, analyzed, combined, processed and transferred to an integrated platform as shown in Figure 37, to be used in the human settlement.

Upon completion of the Triple Nexus model as shown in Figure 56 (Appendix D), the model is tested on its capacity to process the Nexus data based on the new approach, and execution of the optimization simulation yielded 67% satisfactory results. This demonstrates that processing Nexus data following the Triple Nexus Framework has improved by 67% (500 more data per time).

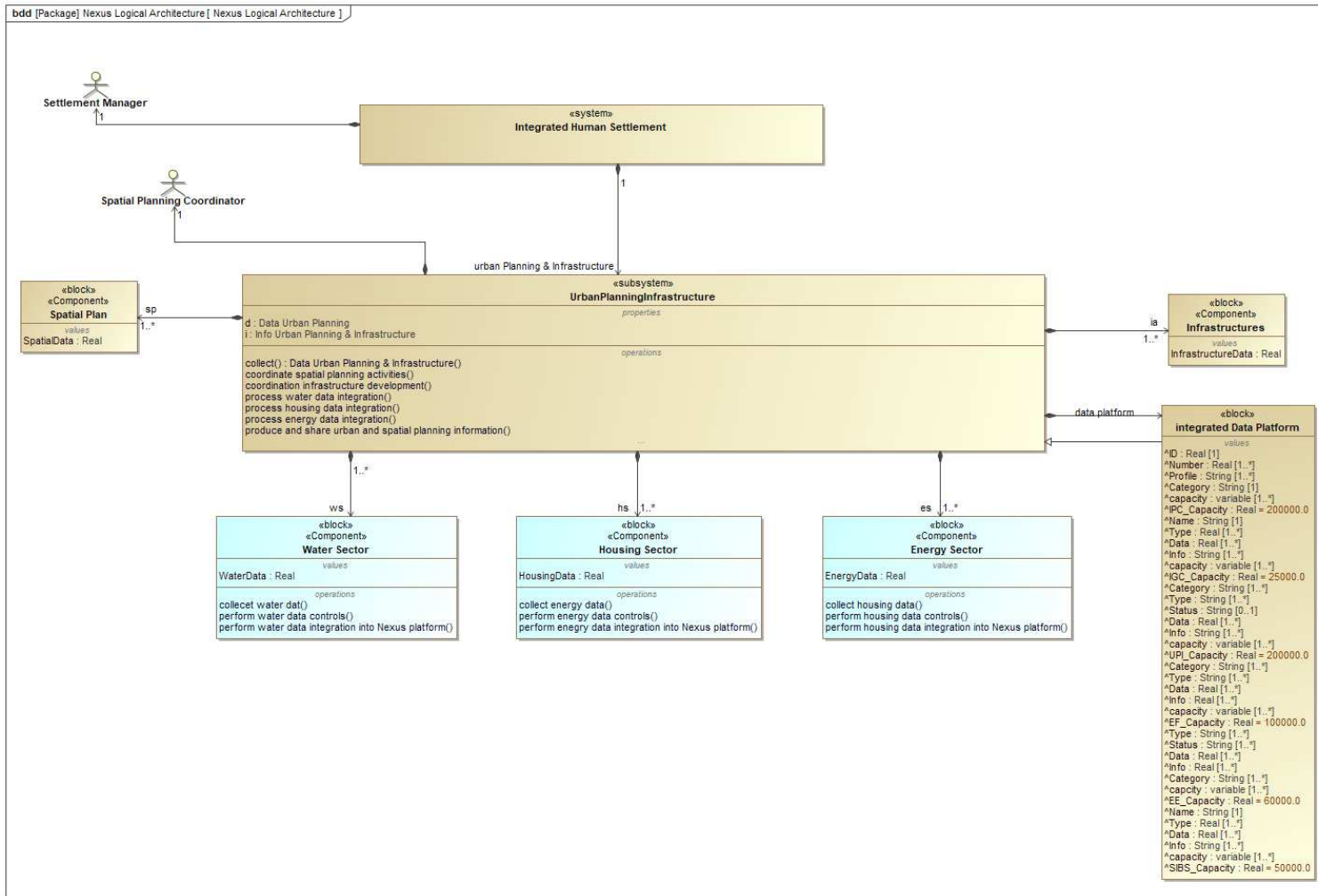


Figure 35: SysML Block Definition Diagram showing the Nexus Integrated Data Platform

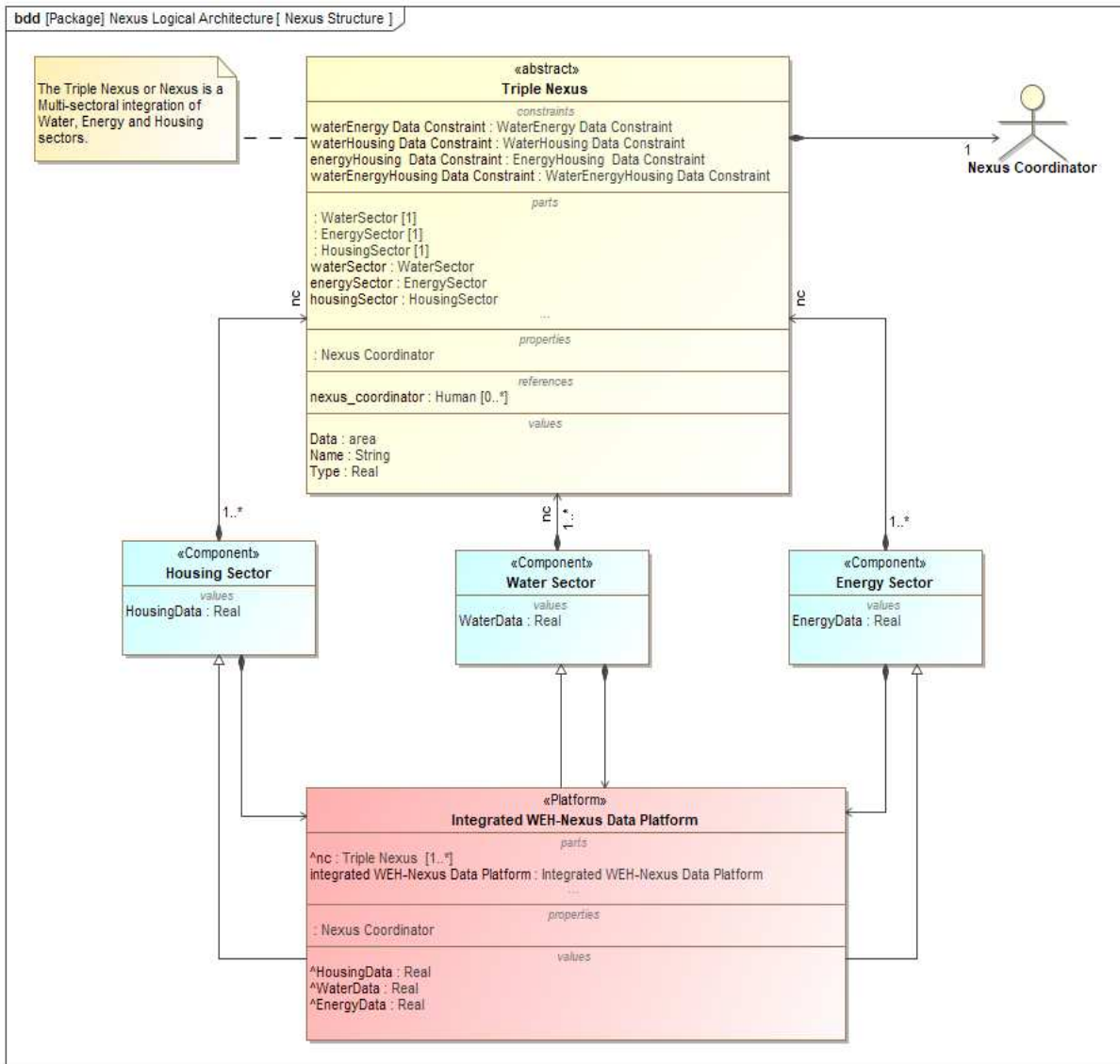


Figure 36: Simplified SysML Block Definition Diagram showing the Nexus Integrated Data Platform

Figure 36 shows a high-level illustration of the proposed Triple Nexus model. The diagram presents states through which the Triple Nexus goes through as presented by the structure in Figure 37. Data sources are the starting point through which data is produced by various means such as sensors, cloud-sourcing, etc. Data will then be sourced and stored at the data block level presented as a Nexus data platform.

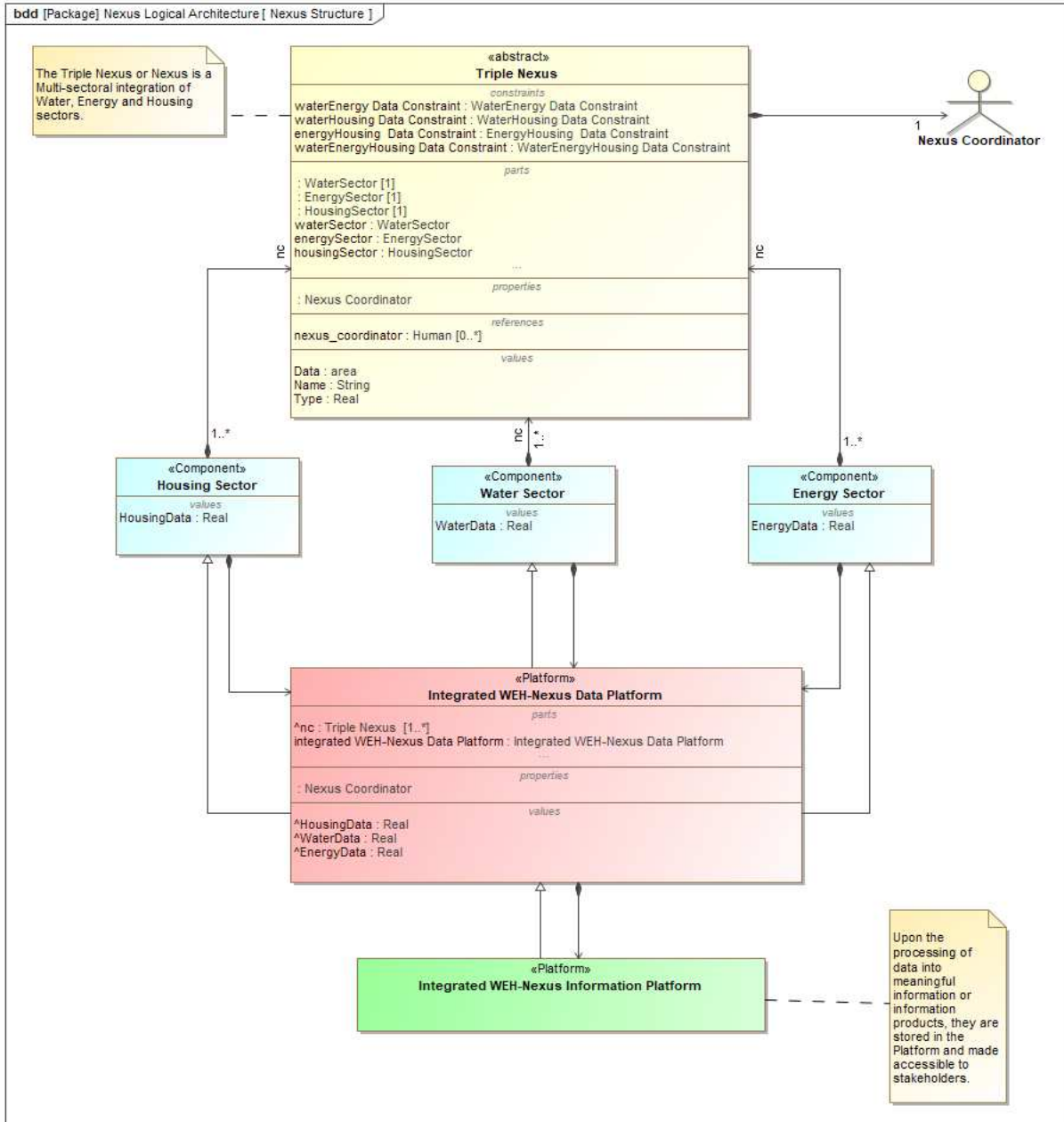


Figure 37: SysML Block Definition Diagram illustrating the Nexus Information Platform

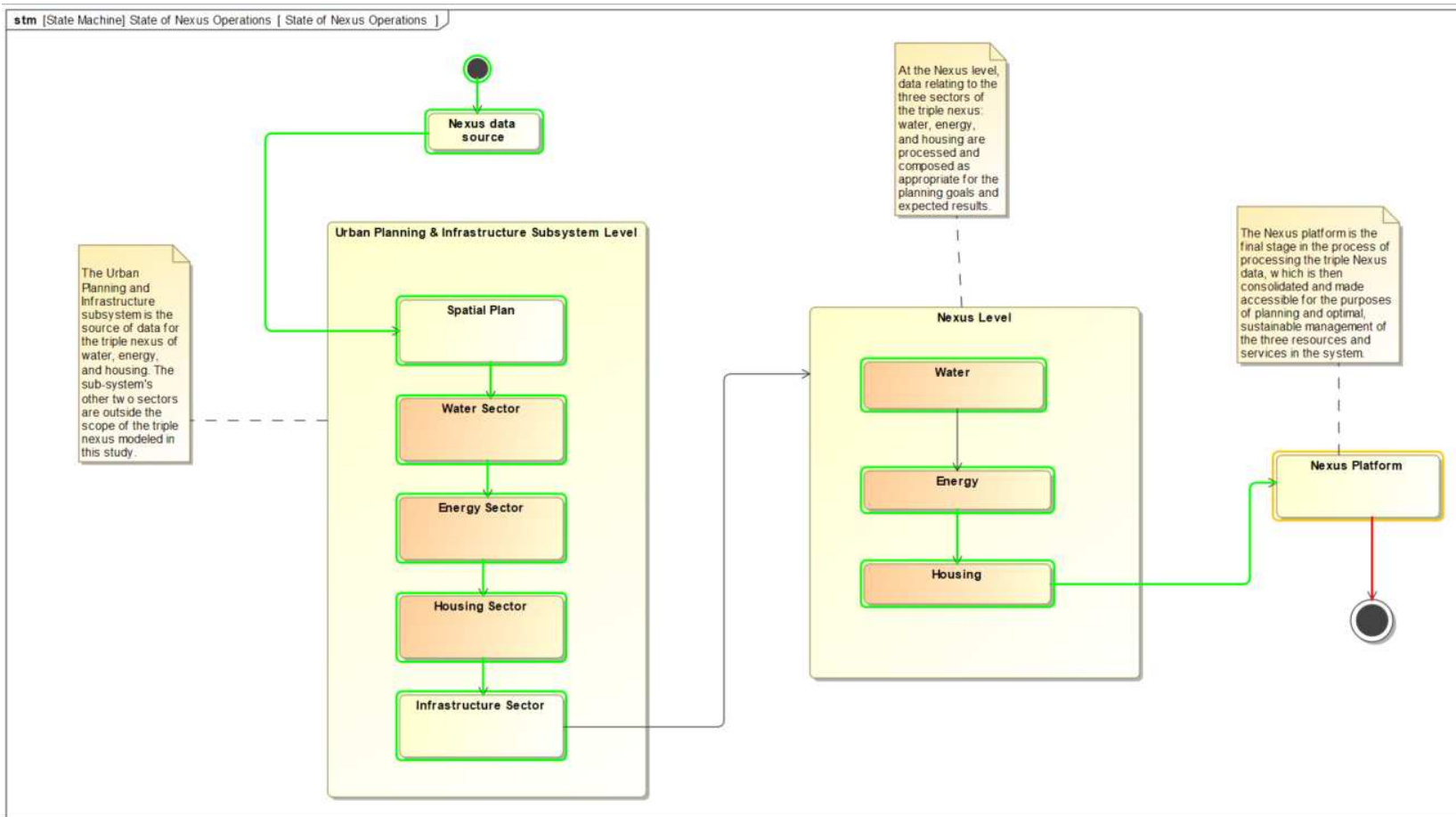


Figure 38: SysML State Machine High Level Illustration of the Triple Nexus Operations

5.5. Triple Nexus Optimization Analysis

The optimization of the Triple Nexus Framework aims to demonstrate the improvement in data processing between the current approach and the proposed Nexus approach through model simulation. As shown in Figure 51 (Appendix B), the optimization analysis process is carried out for Nexus data processing.

It consists of two parts: (1) data generation based on the current approach and (2) data generation based on the Nexus data integration approach. Data processing is used as part of the Nexus analysis for both requirements. The next step is to model the data processing operations, which are performed in the Sequence Diagram shown in Figure 52 (Appendix B). The model is run over a two-month period as an indicative Nexus processing cycle. Thus, up to a two-month period, the single flow is simulated. The Activity Diagrams show the decrease in property iterations, the Sequence Diagram illustrates data processing, and the operation is repeated if iteration >0 . There are also two ‘‘Actions’’ elements which are used to randomize the duration of the current processing (current state) and the duration of Nexus controls processing. The duration of the current state is chosen to be from 0 to 3 days, and the current of the nexus controls process is assumed to be from 0 to 30 days. The second Action of analysis is that the simulation is executed over a year period. So, when a cycle is run, the total is increased by the cycle of the Action one (Duration of current state and duration of Nexus checks).

Upon completion of the simulation, the duration of the current approach (state) per year and the duration of Nexus checks (or controls) per year are executed. There are two possibilities: Current state of data processing (current approach) and Nexus data processing (proposed new approach). The aim is to demonstrate the difference between the performance of current processing and the proposed new data processing. The Activity Diagram (Figure 54, Appendix C indicates

the duration of the Nexus execution assumed to be equal to 1 day, while it is assumed to be from 0 to 30 days for the current approach (Figure 53, Appendix C). The Sequence Diagram (Figure 50, Appendix B) is simulated for all cycle of the year. The sequence diagram is used to model the system optimization simulation process. The parameterization assumption of the model is that many data processes can be executed at the same time on the basis of a single request. This is demonstrated by the analysis carried out with multiple processing multiplicities assumed to be 10, and the model run reveals that 10 data processes are executed at the same time. The execution presents the results of both configurations, as shown in Figure 57 (Appendix D). The requirements are satisfied after the 7th simulation. The results demonstrate that the model works and is capable of processing the proposed Nexus integrated data, more than one million variables per year and rejecting (quality checks) less than 0.005 million variables per year.

The results demonstrate that the Nexus data optimization simulation is satisfactory. The results (Figure 57, Appendix D) show an improvement in data processing based on the Nexus approach, which improved the process by 67% (500 more data per time). The Parametric diagrams (Figures 55, Appendix C; and 56, Appendix D) show the equations developed to produce the data and corresponding times.

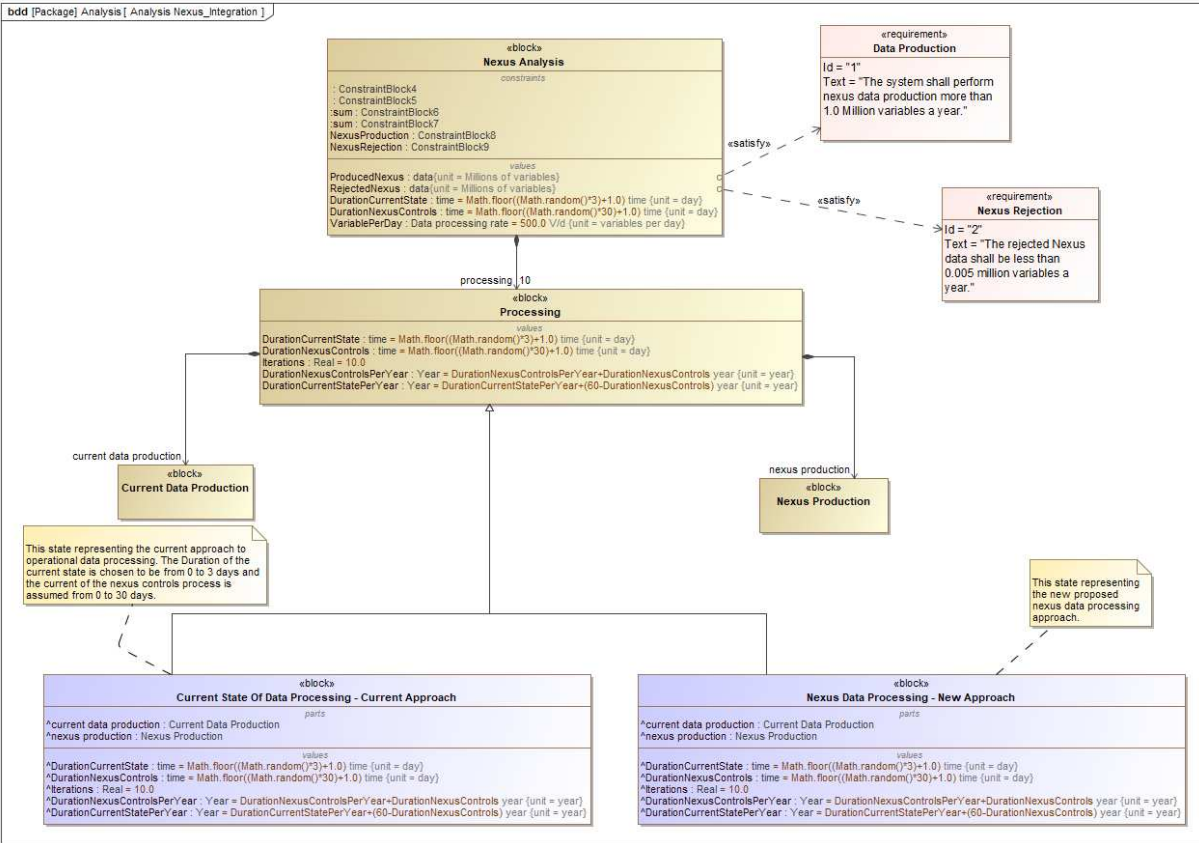


Figure 39: SysML Block Definition Diagram showing the Triple Nexus Data Processing

Figure 56 (see Appendix D) shows the configuration results after the Nexus model optimization simulation. It demonstrates the capacity of the Nexus model to process data in accordance with the new approach, and the optimization simulation yielded 67% satisfactory results. The remaining 33% could be achieved by increasing the Nexus data processing time (or duration) to improve the efficiency of the framework.

5.6. Triple Nexus Framework Modeling

5.6.1. Behavioral Modeling

To model the Triple Nexus Framework, while a structural model captures the hierarchy of the system and the relationships between internal elements, it cannot model the flow of data inputs and outputs through a sequence of actions, which implies modeling behavior [96]. For this purpose, I used the SysML Activity Diagram as an Activity Diagram in SysML can capture the data flows of water, energy, and housing, and represent a set of actions for the execution and processing of data up to the Platform. Figure 58 shows the Activity Diagram of the Triple Nexus Framework behavior model, which captures the data flow from within the water, energy, and housing sectors. It also illustrates the explicit assignment of behavioral partitions, representing parties responsible for executing and processing tasks.

Data are obtained from needs assessments, then transformed into composite data, whose quality is controlled by Nexus experts. Sector data is analysed and transformed into meaningful multi-sector data, either sector-specific or composite in the form of nomenclatures. Finally, the selected composite data and other sector-specific data are transformed into meaningful data to be used by Nexus experts when reconfiguring the integrated platform and Nexus database. As the behavioral model of the Triple Nexus Framework captures the main actions common to the Nexus realization process, it can be reused for other specific design scenarios. In addition to the Triple Nexus Framework behavior model, I developed a decision support behavior model to capture how decisions are made. As shown in Figure 41, the starting point is to trigger the operations required by the Triple Nexus Framework. On the technical side, a parametric model is run using databases and a solver. As described in Chapter 5, the solver supports the execution of the parametric model. To apply the operating logic, requirements are examined to determine whether they are satisfied.

If not, advice on implementing diversity in process reconfiguration is provided based on eventual changes and modifications. After several iterations, the decision support process is completed when the Nexus data processing objectives are consistent with requirements and standards, and the platform operation is achieved through trade-off analysis. The details of the simulations are explained in greater detail in Chapter 6 as part of the answer to the third research question.

5.6.2. Constraint Analysis

As shown in Figure 41, constraint analysis is required to provide decision support to the Nexus [104]. Using constraint blocks, a Parametric Diagram can be drawn up to model the connections between constraint parameters and value properties of the Nexus data processing reconfiguration system. The Parametric Diagram links the relevant block properties and model parameters. Modeled as mathematical equations, the constraints in the Parametric Diagram can be solved by solvers to enable analysis. When the parametric simulation is executed, the constraint statement checks whether the requirements are met.

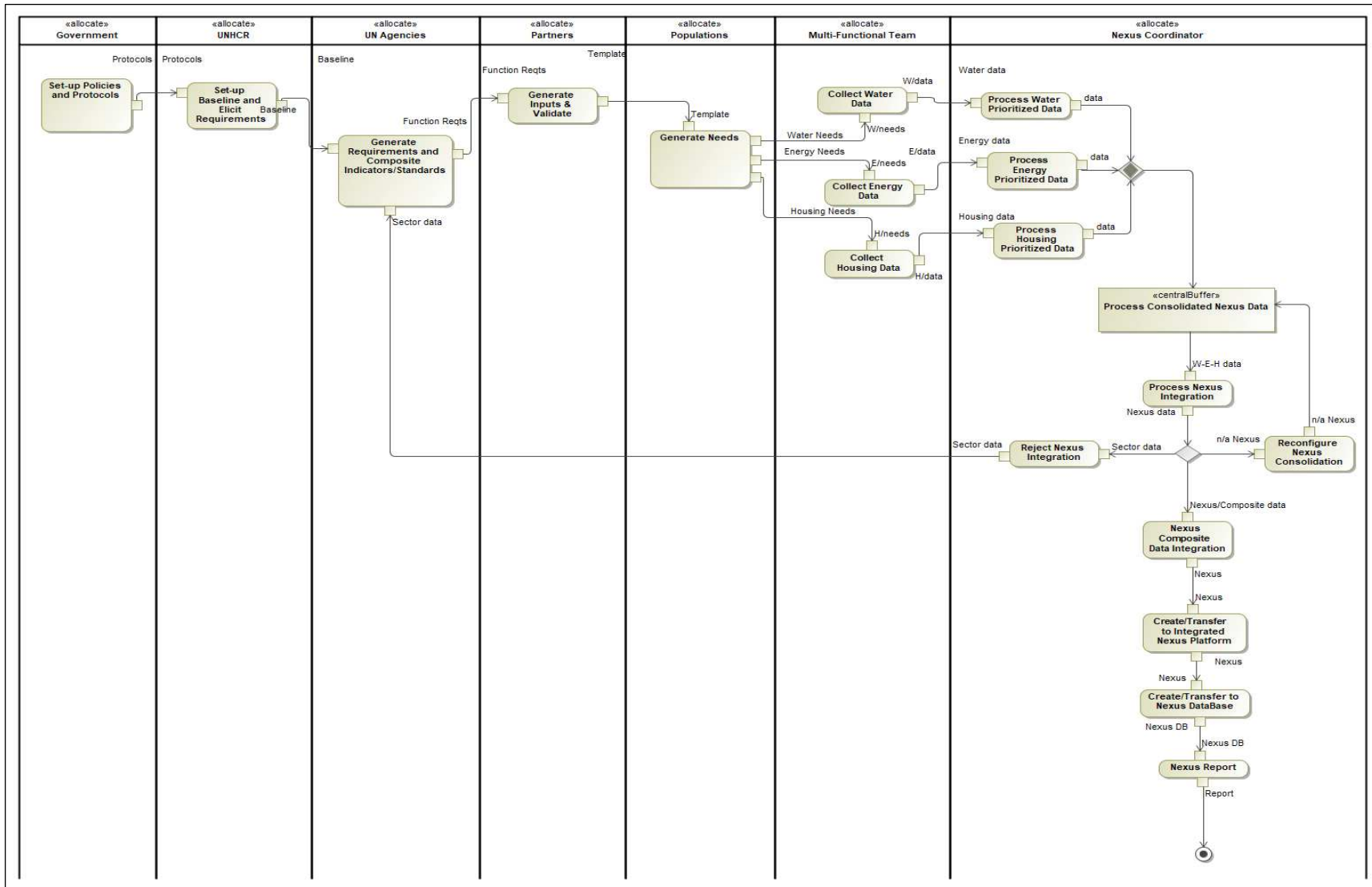


Figure 40: SysML Activity Diagram for Nexus Framework Behavior Model (Adapted from [104])

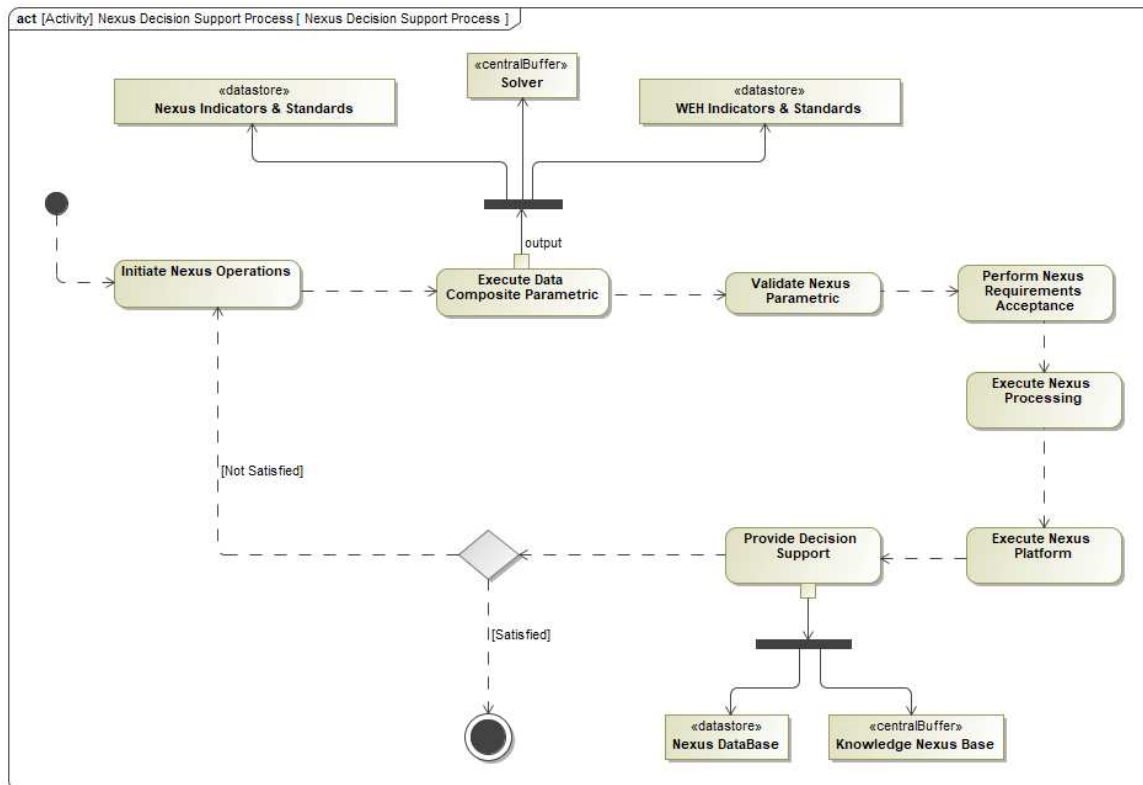


Figure 41: Activity Diagram for Nexus Decision Support Process (Adapted from [104])

5.7. Structured Interview Results

5.7.1. Introduction

Before starting the interviews, the questionnaire and Q-Statements were submitted to the participants in accordance with University’s requirements (Protocol #5005 | v1). Having developed the settlement model and the TNF, this Section presents the evaluation and validation steps that followed. To validate the two models, I conducted structured in-person and virtual individual interviews with twenty (20) participants from UNHCR staff and international humanitarian organizations from diverse backgrounds, comprising senior managers, subject matter experts (SMEs) in the water, energy and housing sectors, and urban planning, to assess the

effectiveness of the proposed model and framework against UNHCR's approaches. The aim is to reach a consensus on the operability, adaptability, and applicability of the proposed Human Settlement System model and the Triple Nexus Framework.

The results, combined with an experimental application in an existing settlement in Kenya, shed light on their adaptability to humanitarian operations. The results led to recommendations for adoption and scaling in Section 5.7.6, and a complete overview of the structured interview is provided in Appendix F. In addition, a participatory and interactive approach (Q-Statement) using the methods described in [105] was organized with the same groups of participants. The outcomes demonstrated that the Human Settlement System approach and the Triple Nexus Framework will make a significant contribution to more effective and sustainable human settlement planning on the one hand, and on the other, to a much improved process of composite data construction (multi-sector data), processing, simplified management and sharing within the integrated human settlement in which the triple nexus is implemented.

5.7.2. Organization and Interview Process

Structured individual interviews were conducted in October 2023 in person in Mali in the capital Bamako, and virtually with UNHCR staff from the technical departments of water, energy, housing, information and data management and other settlement managers directly involved in the design and management of humanitarian operations, who have research knowledge and can provide expert views and perspectives on the subject. A full list of interviewees can be found in Appendix G. In practice, I interviewed two Senior Managers and first presented the models, followed by a simulation demonstration, to obtain feedback on the added-value that the models could bring to UNHCR operations, particularly from a strategic and policy point of view. In addition, a representative of the Malian government acting as a settlement coordinator was

interviewed to gain his perspective on settlement management and coordination. Three information management officers from UNHCR in Mali were also interviewed in person. The remaining fifteen participants were interviewed virtually via Zoom and Microsoft Teams. The interview was conducted in accordance with [106, 107] and each interview lasted 2–3 hours, with the following agenda:

- Background (5 minutes)
- Introductory question (5 minutes)
- Transition questions (15 minutes)
- Proposed Human Settlement system and Triple Nexus Framework demo (15 minutes)

A live model simulation demonstration was done using Cameo System Modeler software.

I used the models demo to make participants get a live execution of the framework model and how the simulation can be performed by any trained staff who does not require a pre-requisite in systems modeling. Participants received the Questionnaire and the models tutorials prior to interviews.

- Interview questions (60 minutes)
- Summary questions (15 minutes)
- Concluding questions (15 minutes)

I started the interview with a introduction to the research context followed by a transition to the interview questions, then a demonstration of the models emphasizing on the processes and results. Qualitative and quantitative methods were applied simultaneously, with qualitative techniques to explore the views, perspectives, suggestions and interaction with participants, as well as quantitative techniques (standards compliance, model parameterization, correlation and factor analysis). Qualitative and quantitative aspects are intertwined throughout the interview process.

The entire interview process was recorded for later analysis and interpretation. During the interviews, I facilitated discussions with participants by asking questions as follows:

1. What are the main challenges and constraints faced by UNHCR operations in the process of collecting, analyzing, storing, sharing and managing operational data (water, energy, shelter) that hinder evidence-based decision-making for the design and management of humanitarian settlements?
2. How can operational data on water, energy and housing needs be interconnected, cross-referenced and integrated to enable a more comprehensive and cross-sectoral analysis?
3. Are there gaps in the integration of multi-sectoral data for decision-making in the design and development of human settlements?
4. During the design process of a humanitarian settlement, how does UNHCR coordinate the collection and sharing of sectoral data across different technical units, i.e. water, energy, housing, taking into account potential interactions between the three sectors?
5. What key water parameters could influence the energy and housing sectors, and vice versa, to ensure the effective design of humanitarian settlements?
6. What are the key energy parameters that could influence the water and housing sectors, and vice versa to ensure an effective design of humanitarian settlements?
7. What housing parameters could influence the water sector and vice versa to ensure an effective design and management of humanitarian settlements?
8. How does UNHCR ensure an effective flow of data and sector requirements between the three sectors of water, energy, and housing, which could lead to multi-sectoral gaps identification for an effective decision-making process?

9. What should UNHCR do to address gaps and issues relating to data access and dissemination at different planning scales (macro, meso and micro)?
10. Given the challenges and gaps thus noted, how do you think the proposed model framework integrating water, energy and housing data could contribute to improve decision-making and performance in the design and development of humanitarian settlements?
11. What obstacles (technical, regulatory, financial, political) would the proposed decision-making framework and triple nexus application likely face?
12. What could be the benefits of implementing such a decision-making framework?

A second round of validation questions were given as follows:

1. Based on this conceptualization of a human settlement, what would you say about the six proposed subsystems to ensure a best functioning?
2. Would you validate these six subsystems as vital to a human settlement?
3. How do you rate the relevance of composite indicators in effectively realizing the goal of integration and interrelations between the three sectors?
4. Do you agree that composite indicators across water, energy and housing can improve the impact on beneficiaries?
5. How do you think the proposed model framework for integrating water, energy, and housing data could improve decision-making and performance in the design and development of humanitarian settlements?
6. What barriers (technical, operational, financial, policy) would the proposed Nexus Framework and application would you expect this to face?
7. Would you validate/approve the proposed framework as a basis for testing in real humanitarian and/or development contexts?

To analyze the participant's discussion in answering these questions, I used Liamputtong's group components of what, who, and how for analysis [106, 107] to provide the participants' evaluation of the framework's impact on decision-making.

To evaluate the Triple Nexus Framework against UNHCR's current data processing methods, I interviewed UNHCR's Chief Information Officer who oversees operational data management in the application of the Q-statement methodology.

The Q-Methodology was applied to investigate the objective views of participants involved in operational data management and settlement design. To do this, participants were presented with statements called the Q-set. Participants, called the P-set, were asked to rank-order the statements from their technical knowledge and individual point of view, mostly using a quasi-normal distribution. They provided objective acknowledgment and professional perspectives by 'Q-sorting' the statements.

In application of the Q-Set of statements, each statement is linked to one of the categories that lead to the conceptual framework. For this research, I considered a Q-Set of 39 statements for the interviews. (In general, a Q-Set of about 40 statements is considered satisfactory). Statements are formulated as responses to the question "To what extent does the proposed nexus framework meet UNHCR's needs for operational data management?" (S. Watts and P. Stenner, "Doing Q methodology: theory, method and interpretation," *Qualitative Research in Psychology*, vol. 2, no. 2, pp. 67-91, 2005). Before the interviews, the 39 Q statements were validated in a pilot interview phase with three respondents selected among UNHCR's experts.

During the interviews, each participant was asked to prioritize Q-39 statements from "strongly disagree" to "strongly agree" on a Q-sorting diagram based on the following Q-39 statements:

1. Operational data management for UNHCR's various technical sectors is highly decentralized.
2. UNHCR's current sectoral needs assessment approach to data collection and analysis is decentralized.
3. Sector-specific data management systems exist, illustrating solution-oriented mindset, but with a decentralized approach.
4. UNHCR should make comprehensive use of operational data from the water, energy and housing sectors to better help forecast needs and changes.
5. There is a requirement to streamlining UNHCR's operational data and information management systems.
6. UNHCR's technical units should avoid data warehouse approaches, which is are centralized repository of datasets.
7. UNHCR does not currently have integrated and operational sectoral data structures.
8. The root causes of fragmented approaches are that data requirements are sector-specific.
9. Current fragmented approaches do not contribute to efficient management of operational data for water, energy, and housing.
10. Development of integrated technical rules would be more expensive for UNHCR operations.
11. Integration of operational data enables production of meaningful information for decision-making, advocacy, and results.
12. To address the challenges, various options can be explored, such as setting up a data lake where raw data can be extracted from different systems.

13. The system's approach and data interoperability may be difficult to apply across all humanitarian operations.
14. UNHCR technical units should implement system-thinking approach for settlement design.
15. The integration of sector data does not ensure human settlement sustainability.
16. The integration of operational data should be supported by measurement indicators.
17. An integrated sector data management framework lays the foundations for the sustainable development of humanitarian settlements.
18. Current fragmented approaches in the water, energy and housing sectors are implemented by non-experts.
19. The transformation of operational data for water, energy, and housing does not provide added value for decision-making processes in the design of humanitarian settlements.
20. Sector data and information products should be accessible to all partners and humanitarian organizations.
21. The expected results of using integrated data ensure consistency and quality across all sectors.
22. An integrated technical wide rule book would result to better efficiencies in humanitarian settlement.
23. The new framework will reinforce UNHCR's principles and compliance with humanitarian principles.
24. Data collection, storage, analysis and sharing systems can be improved through a system-based framework.
25. The integrated system for sharing and analyzing operational data enables rapid decision-making.

26. Integrated technical-wide rule book would set out protocols for better structure processes.
27. A system framework enables all UNHCR technical units to apply harmonized approaches to data use and management.
28. The use of factual and operational data could be modeled in a system framework through Model-Based System Engineering (MSBE) approach.
29. Using a system framework through model-based systems engineering (MBSE) approaches will impact the human factor.
30. Integrated system framework does not guarantee that all data parameters are considered.
31. Sharing and accessing operational data with stakeholders can be done more effectively.
32. Good knowledge and using water, energy and housing data parameters are very useful to improve quality of flife.
33. Operational data should be integrated and accessible to appropriate audiences in real-time.
34. There is no breach of confidentiality in operational data from the three Nexus sectors.
35. A system-based nexus decision-making framework in water, energy, and housing represents a partial solution that will facilitate optimal use of multi-sector data.
36. This approach will encourage other partners and stakeholders to share their data on water, energy & housing.
37. A systems approach to data integration will improve performance in achieving sustainable development goals in the three sectors.
38. The proposed framework will enhance dynamic cross-cutting impact analysis.
39. The proposed framework will build capacity in standards and demographic data.

As the nature of the interviews is explorative, applying the Q-methodology was meaningful and has shown its usability in the social complex context [105].

5.7.3. Interviews Results Analysis

During the interviews, all participants were briefed and given general information on the system model and the framework, as well as research expectations before the interview began. Before the start of each interview, an introduction was given (see interview guide), and discussions were interactive and open-ended.

For the analysis, I used Liamputtong's 12 aspects of interaction to analyze the participant's responses with this method. The results of the analysis are presented in Table 8: System and Triple Nexus Framework Interview Analysis [Adapted from 106, 107, 108]

With regard to the "What" component, UNHCR senior management recognized the added value of the nexus framework in terms of budgetary benefits that will have a significant impact on activities programming in water, energy and housing sectors. However, these results will only become meaningful once the programme is monitored and the costs and benefits assessed. Where appropriate, the framework should be generalized and applied to other critical sectors such as nutrition, health and education. At the same time, SMEs recognized the automation potential of the framework, which will improve data prioritization and processing across the three sectors, thereby improving the performance of current data management systems that lack systemic approaches.

Participants also stressed the need for a consistent assessment of the framework's performance against the UNHCR sector's key performance indicators, and for a clear definition of performance measurement for the composite indicators. Although participants unanimously recognized the importance of the framework, 46% (14/20), some did not agree that UNHCR should be fully responsible for managing the platform, but rather the government or an independent entity. In the end, the question was not answered during the interviews. The "Who" and "How" group

components were much more oriented towards senior managers and the government representative regarding the framework implementation. Individual interviews at this level ensured the plausibility of the proposed stakeholder chart in Section 5.2.3, which effectively grants the settlement management authority to the government. This part of the interview finally led to the conclusion that the majority of participants approved the proposed model and framework for adaptation and application. The component group analysis are summarized in Table 8. The results of the group analysis are summarized in Table 8.

Table 8: System and Triple Nexus Framework Interview Analysis [Adapted from 106, 107, 108]

Group component	Aspects for analysis	Analysis Results
What?	<p>What aspects or issues raised on the proposed water, energy, and housing integrated decision framework that produced agreement?</p>	<ul style="list-style-type: none"> - Senior managers recognized the added value of the nexus Framework relevant for rationalisation of operations. - Need for generalization of the Framework and its application to other relevant sectors such as nutrition, health, and education. - SME acknowledged automation of the Framework to optimize prioritization methods as an improvement to current systems. - Request to include core indicators of SDGs 6, 7 and 11 to highlight linkages between humanitarian and development indicators. - Anticipate potential barriers that could hinder the implementation of the Framework with all indicators, as some countries restrict access to some data. - The question of the responsibilities of the platform manager was raised, with the recommendation that the manager should have the capacity to ensure consistent data quality assurance across all three sectors. - For the integrated system, it was suggested that civil society could be considered as a key component, in the Institutional or Population subsystems. - It was also suggested to clarify at which stages the integrated system model could be applied and the Framework implemented, given that the different sectors do not have the same importance and funding. - Need to test or implement the model and Framework in emergency, transitional and long-term contexts to look for possible adaptations and areas of improvement.
	<p>What statements seemed to evoke consensus?</p>	<ul style="list-style-type: none"> - Recognition of the Framework as an enhanced planning and anticipation tool in line with UNHCR's ongoing multi-sector realignment reforms.

		<ul style="list-style-type: none"> - Usefulness of the Framework in the settlement transformation process with emphasis on the system planning approach. - Shift towards more effective integrated outcome-based solutions. - There is no similar integrated multi-sector framework in-house and it needs to be further tested in real humanitarian settlement contexts. - Addressing the system approach in settlement planning from the outset as an improvement to the current general settlement planning approach. - How to ensure data tracking and indicator performance measurement?
	<p>What statements seemed to raise confusions or contradictions?</p>	<ul style="list-style-type: none"> - Some confusions have emerged, especially on how to ensure intra-operability between the sectors of the Framework? - And how to achieve real interconnection with other sectors whose implementation uses the cash transfer method? - How to make sectoral and composite data work in the unified database (integrated platform), and how to ensure that they are shared in accordance with the policies and needs of each stakeholder? - Challenges in terms of capacity to acquire the software to operate the Model and the Framework permanently in the Organizations. - Some contradictions have emerged in the governance of the Framework on the need to identify who should authorize the execution or implementation, given the too regular turnover in humanitarian contexts. In addition, how to connect or link the Framework to existing internal databases and to DIMA?
	<p>What common experiences or recommendations were expressed?</p>	<ul style="list-style-type: none"> - Consider the possibility of including ‘‘Industrial sector’’ as a component of the Urban Planning subsystem. - Introduce the Model and Framework as an organizational planning framework for its standardization and ensure standards are well incorporated and linked to standard operating procedures.

		<ul style="list-style-type: none"> - Establish links and standardize common experiences with other agencies that share data with UNHCR. Other agencies adopting the same or similar framework will allow for integrated inter-agency data exchanges. - Ensure better performance of the Framework by establishing consensus with the population biometric database and excluding non-shareable private information.
	Did the interview process generate new insights or precipitate an exchange of information from participants?	Yes. Participants gained a better understanding of the proposed Framework and started discussing how to align it with existing data collection tools and templates and minimize human interference. Other points were raised regarding how to capture water and energy quality indicators to have comprehensive information on these sectors. In addition, concerns were raised about how the proposed framework could influence UNHCR’s staffing change in the three sectors that are combined into “one” from a settlement management perspective. The majority called for its implementation in all three humanitarian contexts of emergency, transition, water and stability, to facilitate rapid decision-making processes.
Who?	Who will benefit directly and indirectly from the application of the proposed integrated decision framework?	Stakeholders include operations departments, who will benefit from the budgetary advantages of implementation; data managers, who will find it easier to process and share data in real time; and external relations departments, who will have access to information useful for advocacy.
	Who could be the key decision-makers to facilitate the implementation of the proposed framework?	Governments entity in charge of settlement management and UNHCR Seniors managers from Country Operations.

	Who has suggested or demonstrated aspects that differ too much or too little from the proposed framework or parameters that are considered?	Senior management and two other participants recommended that the Model and Framework be presented and demonstrated to other UNHCR's departments and some external stakeholders to take their views into account, which would facilitate further implementation. The government representative suggested that technical departments in countries, such as urban planning, water, energy and housing, could also be consulted to reach a broader consensus. Given that "often people are afraid of change" and some organizations do not like to share their data, it was agreed to hold bilateral discussions if necessary.
How?	How did participants adhere to the solutions proposed by the WEH Decision Framework?	Individual interviews and especially the live demonstration of the Model and Framework in operation generated broad acceptance among the participants as a solution to the challenges currently facing operations with ad hoc and parallel management approaches. They adhered moderately to the discussion topics and were able to discuss each topic at varying lengths.
	How did participants respond to the ideas?	Participants responded positively to questions during the interviews and demonstration and were curious to see the results, contribute constructively to discussions, and provided helpful feedback.
	How do participants get involved in implementing these proposed solutions?	Expectations were raised about the implementation of the Framework, which promises to solve data processing difficulties. However, many tools are currently being tested, without similar results.
	How do participants see the proposed framework being considered in future humanitarian settlement planning cycles?	Concerns and comments raised during the interviews will be taken into account in the implementation phase of the Framework, with the prior agreement of Country Operations. The results and comments will be used to generalize the Framework in humanitarian cycle planning.

5.7.4. Findings and Conclusions

Structured individual interviews are conducted to evaluate the acceptability of the novel system and the triple nexus decision-making framework. The aim is to present this proposed framework to an audience of practitioners and decision-makers in order to obtain their observations, which would help build a consensus on the Triple Nexus Framework's operability, particularly in the context of UNHCR operations. Following the interviews, the main conclusions drawn from the results in Table 8 are as follows:

- A similar integrated system and TNF approach linking the water, energy and housing sectors had not previously been tested at UNHCR, and represents a new tool that would fill important gaps in the processing of multi-sector data for planning purposes.
- The proposed model-based TNF, when compared to UNHCR's standard settlement design guidelines and the state of the art, allows for improved complex multi-stakeholder decision-making.
- Near-unanimous recognition that the Model and TNF could contribute to "operational centrality", "multi-sectorality" and nexus reforms in humanitarian operations. These results demonstrate that the proposed Model and Framework could be a powerful complement to the existing master planning approach, addressing many of today's challenges.
- The TNF should establish links or connections with other data management systems within UNHCR and identify similarities with a view to standardizing the operational data processing.
- SME and IMO requested that training on the application of the software (No Magic Cameo System Modeler) be undertaken to build a pool of internal capacity.

Recommendations will need to be developed to apply the Model and Framework in a real-world context, in order to better assess the need for customization in relation to UNHCR's three operation planning cycles: emergency, transition and stability (or development).

These results represent the views, observations and recommendations of practitioners and technical groups in the human settlement sector, enabling the operationality and feasibility of the proposed Model and Framework, thus contributing to answer Research Question 2.

The outcome of this research task is that the Model and Framework are currently in demand as tools to advance the state of change in ongoing approaches, particularly within UNHCR. I included these findings in the recommendations for adoption and scaling up outlined in Section 5.7.7.

5.7.5. Application of the Q-Statement Methodology

For the Q-Statement, I conducted the analysis based on the Kaiser-Gutmann criterion⁹, significant loading factor, and a less strict application of Humphrey's rule¹⁰. This research methodology is applied to illuminate the agreement and differences between the participants' perceptions. I applied this methodology in this research as a combination of qualitative and quantitative research techniques that helped identify the common or divergent opinions of the participants on the 39 predefined statements. This methodology complements the structured interview by providing a means of discovering the perceptions of the ten selected participants and providing them with additional information. The qualitative aspect of the Q methodology allows for a focus on how and why participants think the way they do. The main objective is to discover

⁹ The Kaiser-Guttman Criterion is used to define nFactors to conduct a Q-methodology. The Kaiser-Guttman Criterion states that factors should be retained if they have an eigenvalue greater than 1.00. (To understand Q-methodology, visit: <http://www.qualresearchpsych.com/>).

¹⁰ Humphrey's rule is used to define nFactors to conduct a Q-methodology. Humphrey's Rule states that factors should be retained if the cross-product of the two highest factor loadings exceeds twice the standard error. This interface automatically determines the cross-product of the two highest factor loadings for each factor, which is displayed under Humphrey's Rule in a table. ((To understand Q-methodology, visit: <http://www.qualresearchpsych.com/>)).

different thinking patterns and not to count the number of participants who think the way they do [134]. The quantitative aspect involves the use of factor analysis techniques as a means of grouping like-minded participants [134].

5.7.5.1. Q-Sort Process

Ten (10) participants selected from the twenty (20) respondents are asked to sort the Q-statements into a predefined set of categories, ranging from “Most Agree” to “Most Disagree.” As shown in Appendix F (Q-methodology & Q-Sort Diagram), the participant responses are used to sort the survey items and adopt the shape of a normal distribution. There are fewer statements that can be placed at each end, allowing more to be placed in the neutral zone of the scale. In order to lend credibility to the results, 10 participants were selected based on their backgrounds and experiences in human operations, particularly in the water, energy and housing sectors or as decision-makers. The graph below shows the composition of respondents to the Q-statements.



Graph Presenting the composition of the Q-Statement Participants.

The Q-Statement is administered to each participant and their individual rank-ordered statements are then recorded. The resulting data matrix reflects the participant’s sorting arrangements in the column with the survey item statement along the row. The ranking level of each item is then entered into the data matrix to allow factor analysis.

Table 9 illustrates the Q-Sort for Participant 1 (P1). Participant P1 ranked statements 20 (Sector data and information products should be made available and accessible to all partners and stakeholders.) and 21 (The benefits of using integrated data ensure consistency and quality across all sectors.) a +4, indicating a strong agreement on the importance of access to all sector and quality data. Conversely, statements 1 (Operational data management for various technical sectors is highly decentralized) and 3 (The current data management system works well, and sector-specific data management systems exist) were rated a -4, indicating perceptions of decentralized and sector-centered state of data management.

Table 9: Q-Sort for Participant P1

Q-Sort Grid for Participant 1									
		Disagree			Neutral		Agree		
Raw scores	(-4) Most	(-3)	(-2)	(-1) Least	(0) Neutral	(+1) Least	(+2)	(+3)	(+4) Most
Statement #	1	22	8	18	19	26	31	37	20
	3	6	15	2	38	17	35	24	21
		9	33	29	23	30	27	36	
			7	5	10	14	12		
			25	4	32	39	13		
				34	11	16			
					28				

Data from the 10 participants were collected and entered into a data matrix as presented in summary Table 10. Following the Q-methodology process, individual participants were listed along the column and Q-statements along the row.

Table 10: Summary Q-Sorts by the 10 Participants (Respondents)

Participant	1	2	3	4	5	6	7	8	9	10
1	4	4	-4	4	-3	4	-1	-1	1	1
2	-1	3	-2	0	-4	2	1	2	2	2
3	-4	1	-3	-1	-3	-3	-2	2	1	-1
4	-1	4	1	3	1	3	-1	-2	-2	4
5	-1	0	3	3	2	4	1	0	1	0
6	-3	3	-3	0	0	-2	-1	-1	-2	-3
7	-2	-2	4	0	3	3	-2	0	-1	-1
8	-2	-2	0	1	0	2	4	2	2	4
9	-3	2	-1	2	2	3	2	1	2	0
10	0	1	3	2	3	2	3	4	3	3
11	0	3	-2	4	4	-1	-2	-2	-3	-4
12	2	0	2	4	2	1	3	3	4	3
13	2	-1	2	0	2	1	2	1	3	2
14	1	1	0	1	4	2	4	1	1	2
15	-2	2	-3	2	0	-3	0	-3	-3	-4
16	1	1	1	-1	1	1	2	1	3	0
17	1	-4	1	-2	-2	2	2	1	1	2
18	-1	-4	-2	-1	-1	-4	-4	-3	-4	-2
19	0	-2	2	0	1	1	1	3	4	2
20	4	2	1	-1	1	1	3	-1	0	-1
21	4	1	1	1	-2	0	1	4	-2	1
22	-3	1	-1	0	0	-2	1	-2	1	0
23	0	-3	-1	-1	0	1	-1	2	0	1
24	3	2	-2	2	2	0	1	0	0	-3
25	-2	-2	0	3	3	0	0	2	0	1
26	1	2	-1	0	0	-1	0	0	0	-3
27	2	0	2	2	0	-1	0	-2	0	-1
28	0	0	-2	-1	-3	0	-2	-1	0	0
29	-1	0	-1	-3	-4	-4	-4	-3	-4	-2
30	1	-1	-1	-2	-1	-3	-3	-4	-3	-2
31	2	-1	0	1	-1	-1	0	1	-1	-1
32	0	-3	0	-3	-1	0	2	3	-1	0
33	-2	-2	-4	-4	-2	-2	-2	-4	-1	-1
34	-1	-1	0	-3	-1	-2	-3	-1	-1	-2
35	2	-1	2	1	1	-2	0	-1	-1	-2
36	3	0	1	-2	-2	-1	-1	0	-2	0
37	3	-1	0	-2	-1	0	-3	-2	-2	1
38	0	0	4	1	1	-1	0	0	2	0
39	1	-3	3	-2	-2	0	-1	0	2	1

5.7.5.2. Q-Statement Data Analysis

Data analysis in Q methodology involves the sequential application of three sets of statistical procedures: correlation, factor analysis, and the computation of factor scores [134].

5.7.5.3. Correlation Matrix

Therefore, the first step in the data analysis is to generate a correlation matrix of the participants. Table 11 below presents the correlation matrix obtained for the Q-Sorts.

As demonstrated by Brown [Brown 134], it makes no difference whether the coefficients in the correlation matrix Pearson’s r, Spearman’s rho, or other nonparametric measures of

association. In practice, the factoring process begins once a matrix of Q-Sort correlations is provided. The correlation matrix is generated in Excel using the XLSTAT software.

Table 11: Correlation matrix between Q-Sorts.

Correlation matrix (Pearson (n))

Sorts	1	2	3	4	5	6	7	8	9	10
P1	1	0.053	0.248	0.079	-0.035	0.177	0.171	0.095	0.030	0.095
P2	0.053	1	-0.312	0.514	0.100	0.171	0.118	-0.106	-0.012	-0.145
P3	0.248	-0.312	1	0.106	0.412	0.353	0.335	0.371	0.388	0.399
P4	0.079	0.514	0.106	1	0.556	0.431	0.355	0.213	0.236	0.150
P5	-0.035	0.100	0.412	0.556	1	0.335	0.435	0.188	0.247	0.048
P6	0.177	0.171	0.353	0.431	0.335	1	0.559	0.482	0.565	0.653
P7	0.171	0.118	0.335	0.355	0.435	0.559	1	0.635	0.682	0.508
P8	0.095	-0.106	0.371	0.213	0.188	0.482	0.635	1	0.635	0.563
P9	0.030	-0.012	0.388	0.236	0.247	0.565	0.682	0.635	1	0.605
P10	0.095	-0.145	0.399	0.150	0.048	0.653	0.508	0.563	0.605	1

As noted in Table 11, P4 correlates with P2, P5, P6 in the amounts of 0.51, 0.55 and 0.43 respectively. Similarly, P6 correlates with P7, and P10 (0.55 and 0.65 respectively. P4 on the other hand, shows a weak correlation with P1, P3, P7, P8, P9 and P10 in the amounts of 0.07, 0.10, 0.35, 0.21, 0.23, and 0.15 respectively. A quick perusal down the column shows P10 has a fairly moderate correlation with P6, P7 P8 and P9 (0.65, 0.50, 0.56, and 0.60 respectively).

It's worth noting that Q-Sort correlations are rarely interesting in themselves. Indeed, we're not so much interested in the correlation between two people as in the dominant perceptions of the group. the dominant perceptions of the group as a whole. Consequently, the correlation matrix simply represents a phase through which the data pass on their way to factor analysis [135].

5.7.5.4. Factor Analysis

After obtaining the correlation matrix, the factor analysis process begins by calculating a factor matrix and identifying the eigenvalues. The eigenvalues reflect the amount of variation accounted for by the corresponding factor. The relative magnitude of the eigenvalues can essentially be used to rank the importance of factors. By convention for this research, factors with

eigenvalues greater than 0.4 are considered significant while those with lower eigenvalues are considered too weak (or small) to merit serious attention.

The result of the factor analysis is factor loadings. Factor loadings are in effect correlation coefficients which indicate the extent to which each Q-Sort (i.e., participant) is similar or dissimilar to the composite factor array. Interpretations are based on factor scores which reflect the extent of agreement among perceptions related to the individual Q-Sort statements. The indication of several independent factors is evidence of different points of view in the participant-sample. To be clear, a participant’s positive loading on a factor indicates his shared subjectivity with others on that factor, while negative loadings, on the other hand, are signs of rejection of the factor’s perspective.

Based on these results, factor loadings in excess of 0.40 are considered significant. Referring to Table 12 factor 1, the loadings of P6, P7, P8, P9 and P10 (0.397, 0.414, 0.369, 0.408, and 0.0363 respectively) mean that the Q-Sorts in their totality for each participant demonstrates a common perspective or are highly correlated. The eigenvalue of 3.66 is considered significant and thus, factor 1 appears to represent a common viewpoint held by a number of the participants. The eigenvalues for factors 2, 3, and 4 are also significant (1.481, 0.935, and 0.416 respectively).

Factors 5, 6 and 7 appear to be borderline significance (Eigenvalues = 0.218, 0.0061 and 0.030 respectively), do not constitute a large enough group for further investigation. Therefore, the first four factors (F1, F2, F3 and F4) were identified as candidates for further analysis.

Table 12: Unrotated Factor Loadings

Sorts	F1	F2	F3	F4	F5	F6	F7
1	0.089	-0.025	0.033	-0.647	0.390	-0.295	0.185
2	0.031	0.620	0.436	-0.165	0.162	0.368	0.112
3	0.293	-0.228	-0.446	-0.499	0.100	0.474	-0.201
4	0.249	0.508	0.020	-0.111	-0.166	-0.123	-0.617
5	0.285	0.412	-0.688	0.241	-0.084	-0.100	0.258
6	0.397	0.052	0.180	-0.221	-0.460	-0.139	0.311
7	0.414	0.030	0.089	0.180	0.462	-0.272	0.324
8	0.369	-0.187	0.126	0.203	0.284	-0.299	-0.506
9	0.408	-0.143	0.167	0.327	0.155	0.584	0.073
10	0.363	-0.275	0.228	-0.076	-0.497	-0.070	0.051
Eigenvalue	3.666	1.481	0.935	0.416	0.218	0.061	0.030
Variability (%)	36.660	14.809	9.346	4.156	2.177	0.612	0.302
Cumulative %	36.660	51.469	60.815	64.971	67.148	67.760	68.062

According to Q methodology, interpretations are based on factor tables (or factor matrices) and factor scores rather than the factor loadings (as in classical factor analytic techniques) [134]. After checking the weighting of each of the factor loadings, a composite Q-Sort can be discovered for each of the factors. As shown in Table 13 below, these factor tables (or array) reflect an overall Q-Sample for the participants who loaded in humanitarian factor in total. Based on these factor matrices, corresponding distinctive statements were identified as being associated with each factor. This allows to begin to see the pattern of thoughts that emerge from each of the four groups.

Table 13: Factor Q-Sort Values for Each Statement

Factor Arrays/Scores					
No	Statements	F1	F2	F3	F4
1	Operational data management for various technical sectors is highly decentralized.	0.098	0.995	2.794	-0.860
2	The current sectoral needs assessment approach to technical data collection and analysis is decentralized.	0.290	-0.349	2.894	-0.114
3	The current data management system works well, and sector-specific data management systems exist.	-0.824	-0.272	1.325	1.412
4	Humanitarian actors/agencies should make comprehensive use of operational data from the water, energy and housing sectors to better help forecast needs and changes.	0.513	1.417	0.457	-1.390
5	There is a requirement to connect operational data and information management systems.	0.952	0.190	-0.259	-0.955
6	Humanitarian actors should avoid the data warehouse approach, which is a centralized repository of data.	-1.016	1.329	0.326	0.728
7	There are not currently integrated and operational sectoral data structures.	0.342	-0.113	-1.906	-0.723
8	The root causes of current fragmented approaches is that data requirements are defined through sector-specific needs assessments.	1.194	-1.016	0.693	0.627
9	Current fragmented approaches do not contribute to improved and efficient management of operational data for water, energy and housing.	0.888	0.966	0.402	0.832
10	The selection and application of composite indicator data across the water, energy and housing sectors will generate more benefits.	1.920	0.355	-0.484	0.274
11	The development of a set of composite indicators and integrated data would be more costly for humanitarian operations.	-0.615	2.743	-1.387	0.316
12	The integration of operational data enables the production of useful information for decision-making, advocacy and sustainable outcomes.	1.789	0.097	-0.039	0.298
13	Stakeholders need more integrated, reliable data and real-time information for effective responses.	1.207	-0.263	-0.782	0.385
14	All humanitarian (including UNHCR) technical units should implement a systems approach to settlement design and management.	1.377	1.041	-0.878	0.763
15	The concept of composite indicators and the integration of sectoral data do not always guarantee the sustainability of human settlements.	-1.331	1.283	0.278	0.227
16	The integration of operational data should be supported by measurement indicators.	0.818	0.082	-0.030	0.426
17	An integrated framework for managing sector data based on composite indicators lays the foundations for the sustainable development of humanitarian settlements.	0.411	-2.105	0.503	-0.309
18	The integrated approaches proposed in the water, energy and housing sectors can only be implemented by technical experts.	-1.855	-0.649	-1.175	0.412
19	The design and sustainable management of humanitarian settlements should be based on the six sub-systems proposed by the framework: institutional governance, populations concerned, economy, environment, physical settings including technical sectors, and social concerns.	1.221	-0.873	-0.442	0.796
20	Sectoral data and information products should be made available and accessible to all partners and stakeholders.	0.383	0.559	-0.064	-0.763
21	The benefits of using integrated data guarantee consistency and quality across all sectors.	0.225	-0.327	0.984	-1.376
22	An integrated technical wide rule book would result to better efficiencies in humanitarian settlement	-0.226	0.269	0.286	0.824
23	The new framework will reinforce humanitarian principles and operations.	0.117	-0.801	-0.474	0.785
24	Data collection, storage, analysis and sharing systems can be improved through a system-based framework.	0.040	1.495	-0.300	0.440
25	The integrated system for sharing and analyzing operational data enables rapid decision-making.	0.603	0.333	-1.271	1.034
26	An integrated technical-wide rule book would set out protocols for better structure processes.	-0.387	0.742	0.202	0.155
27	A systemic framework enables all technical sectors to apply harmonized approaches to data use and management.	-0.129	0.008	-0.168	-1.037
28	This integrated data approach could be extended to other sectors of humanitarian response.	-0.708	-0.530	1.155	-0.014
29	This integrated data approach could compromise accountability to affected populations.	-2.120	-0.625	0.513	-0.776
30	An integrated system framework does not guarantee that all data parameters are taken into account.	-1.539	-0.073	-0.725	-0.262
31	Sharing and accessing operational data with stakeholders can be done more effectively.	-0.281	-0.384	0.172	-0.423
32	Effective use of the integrated parameters of water, energy and housing is very useful for improving people's living conditions.	0.005	-1.415	-0.075	0.330
33	All humanitarian-related operational data should not be integrated and accessible to everyone.	-1.479	-0.647	0.051	1.273
34	There is no breach of confidentiality in the operational data of the three Nexus sectors.	-1.023	-0.460	-0.588	0.236
35	A nexus approach for water, energy, and housing represents a partial solution that will facilitate the optimal use of multi-sector data.	-0.282	0.007	-1.013	-0.628
36	This approach will encourage other partners and stakeholders to share their data on water, energy & housing more efficiently.	-0.545	-0.576	0.193	-1.109
37	This nexus approach will require additional efforts to implement.	-0.626	-0.350	-0.494	-0.693
38	The nexus approach framework will enhance dynamic cross-cutting impact analysis.	0.504	-0.214	-0.659	-0.535
39	The proposed framework would help build capacity and confidence in the application of standards.	0.090	-1.866	-0.014	-0.603

Note: Values in bold correspond for each observation to the factor for which the squared cosine is the largest

As illustrated in Table 14, participants: P8, P10, P12, P13, P14, P15, P16, P18, P19, P29, P30, P33 and P34 constitute Factor 1. Accordingly, Factor 1 identifies that participants in the group share strong views that the the root causes of current fragmented approaches are that data needs are defined through sector-specific needs assessments and that the application of composite indicator data in the water, energy and housing sectors will generate more benefits. Importantly, the proposed approach enables the production of useful information for decision-making and sustainable outcomes, as well as the sharing of reliable data and real-time information among stakeholders. On the other hand, this group of participants does not see that an integrated system framework will guarantee that all data parameters are considered and that not all operational data related to humanitarian aid should be integrated and accessible to all. Table 14 presents the distinctive statements of Factor 1.

Table 14: Distinctive Statements of Factor 1

Distinguishing Statements for Factor 1		F1	F2	F3	F4
8	The root causes of current fragmented approaches is that data requirements are defined through sector-specific needs assessments.	1.194	-1.016	0.693	0.627
10	The selection and application of composite indicator data across the water, energy and housing sectors will generate more benefits.	1.920	0.355	-0.484	0.274
12	The integration of operational data enables the production of useful information for decision-making, advocacy and sustainable outcomes.	1.789	0.097	-0.039	0.298
13	Stakeholders need more integrated, reliable data and real-time information for effective responses.	1.207	-0.263	-0.782	0.385
14	All humanitarian (including UNHCR) technical units should implement a systems approach to settlement design and management.	1.377	1.041	-0.878	0.763
15	The concept of composite indicators and the integration of sectoral data do not always guarantee the sustainability of human settlements.	-1.331	1.283	0.278	0.227
16	The integration of operational data should be supported by measurement indicators.	0.818	0.082	-0.030	0.426
18	The integrated approaches proposed in the water, energy and housing sectors can only be implemented by technical experts.	-1.855	-0.649	-1.175	0.412
19	The design and sustainable management of humanitarian settlements should be based on the six sub-systems proposed by the framework: institutional governance, populations concerned, economy, environment, physical settings including technical sectors, and social concerns.	1.221	-0.873	-0.442	0.796
29	This integrated data approach could compromise accountability to affected populations.	-2.120	-0.625	0.513	-0.776
30	An integrated system framework does not guarantee that all data parameters are taken into account.	-1.539	-0.073	-0.725	-0.262
33	All humanitarian-related operational data should not be integrated and accessible to everyone.	-1.479	-0.647	0.051	1.273
34	There is no breach of confidentiality in the operational data of the three Nexus sectors.	-1.023	-0.460	-0.588	0.236

Similarly, participants P4, P6, P9, P11, P17, P23, P24, P26, P32, and P39 constitute Factor 2. As a result, Factor 2 identifies that participants in the group share strong views that stakeholders should make full use of operational data from the water, energy and housing sectors to better help forecast needs and changes, and to avoid the data warehouse approach. Furthermore, the group notes that current fragmented approaches do not contribute to improved and effective management of operational data for water, energy and housing, and that such an integrated sectoral data

management framework based on composite indicators lays the foundation for sustainable human settlements development. However, developing a set of composite indicators and integrated data would be more costly for humanitarian operations. This group generally agrees that the new framework will strengthen humanitarian principles and operations, and that data collection, storage, analysis and sharing systems can be improved through such a systems-based framework.

Table 15 presents the distinctive statements of Factor 2.

Table 15: Distinctive Statements of Factor 2.

Distinguishing Statements for Factor 2		F1	F2	F3	F4
4	Humanitarian actors/agencies should make comprehensive use of operational data from the water, energy and housing sectors to better help forecast needs and changes.	0.513	1.417	0.457	-1.390
6	Humanitarian actors should avoid the data warehouse approach, which is a centralized repository of data.	-1.016	1.329	0.326	0.728
9	Current fragmented approaches do not contribute to improved and efficient management of operational data for water, energy and housing.	0.888	0.966	0.402	0.832
11	The development of a set of composite indicators and integrated data would be more costly for humanitarian operations.	-0.615	2.743	-1.387	0.316
17	An integrated framework for managing sector data based on composite indicators lays the foundations for the sustainable development of humanitarian settlements.	0.411	-2.105	0.503	-0.309
23	The new framework will reinforce humanitarian principles and operations.	0.117	-0.801	-0.474	0.785
24	Data collection, storage, analysis and sharing systems can be improved through a system-based framework.	0.040	1.495	-0.300	0.440
26	An integrated technical-wide rule book would set out protocols for better structure processes.	-0.387	0.742	0.202	0.155
32	Effective use of the integrated parameters of water, energy and housing is very useful for improving people's living conditions.	0.005	-1.415	-0.075	0.330
39	The proposed framework would help build capacity and confidence in the application of standards.	0.090	-1.866	-0.014	-0.603

For factor 3, participants P1, P2, P7, P25, P28, P35, and P38 constitute Factor 3 and this Factor identifies that the grouping participants share strong opinions on the current sectoral needs assessment approach to technical data collection and analysis which is decentralized, and that the proposed nexus approach for water, energy, and housing represents a partial solution will facilitate the optimal use of multi-sector data, and ultimately, the nexus approach framework will enhance dynamic cross-cutting impact analysis. Participants in this group, however, suggest that the integrated data approach could be extended to other sectors of the humanitarian response. Table 16 presents the distinctive statements of Factor 3.

Table 16: Distinctive Statements of Factor 3.

Distinguishing Statements for Factor 3					
No	Statements	F1	F2	F3	F4
1	Operational data management for various technical sectors is highly decentralized.	0.098	0.995	2.794	-0.860
2	The current sectoral needs assessment approach to technical data collection and analysis is decentralized.	0.290	-0.349	2.894	-0.114
7	There are not currently integrated and operational sectoral data structures.	0.342	-0.113	-1.906	-0.723
25	The integrated system for sharing and analyzing operational data enables rapid decision-making.	0.603	0.333	-1.271	1.034
28	This integrated data approach could be extended to other sectors of humanitarian response.	-0.708	-0.530	1.155	-0.014
35	A nexus approach for water, energy, and housing represents a partial solution that will facilitate the optimal use of multi-sector data.	-0.282	0.007	-1.013	-0.628
38	The nexus approach framework will enhance dynamic cross-cutting impact analysis.	0.504	-0.214	-0.659	-0.535

Finally, participants P3, P5, P20, P21, P22, P27, P31, P36, and P37 constitute Factor 4 and, therefore, Factor 4 identifies that the grouping participants shares strong views that the benefits of using integrated data guarantee consistency and quality across all sectors, and that the proposed approach will encourage other partners and stakeholders to share their data on water, energy and housing more efficiently. On the contrary, this grouping participants agrees that the current data management system works well, and sector-specific data management systems exist, but the nexus approach will require additional efforts to implement. Table 17 below shows the distinctive statements of Factor 4.

Table 17: Distinctive Statements of Factor 4.

Distinguishing Statements for Factor 4					
No	Statements	F1	F2	F3	F4
3	The current data management system works well, and sector-specific data management systems exist.	-0.824	-0.272	1.325	1.412
5	There is a requirement to connect operational data and information management systems.	0.952	0.190	-0.259	-0.955
20	Sectoral data and information products should be made available and accessible to all partners and stakeholders.	0.383	0.559	-0.064	-0.763
21	The benefits of using integrated data guarantee consistency and quality across all sectors.	0.225	-0.327	0.984	-1.376
22	An integrated technical wide rule book would result to better efficiencies in humanitarian settlement	-0.226	0.269	0.286	0.824
27	A systemic framework enables all technical sectors to apply harmonized approaches to data use and management.	-0.129	0.008	-0.168	-1.037
31	Sharing and accessing operational data with stakeholders can be done more effectively.	-0.281	-0.384	0.172	-0.423
36	This approach will encourage other partners and stakeholders to share their data on water, energy & housing more efficiently.	-0.545	-0.576	0.193	-1.109
37	This nexus approach will require additional efforts to implement.	-0.626	-0.350	-0.494	-0.693

5.7.6. Conclusion of Q-Statement Application

In summary, the analysis revealed four patterns of thinking: one stresses that the root causes of current fragmented approaches are that data needs are defined through sectoral needs assessments, and that the application of composite indicators in the water, energy and housing

sectors will generate more benefits. It is important to note that the proposed approach enables the production of useful information for decision-making and sustainable results, as well as the sharing of reliable data in real-time (Factor 1), while the other focuses on the full use of operational data to forecast needs and changes, and the cost of developing a set of composite indicators and integrated data management (Factor 2). The other values the nexus approach as a partial solution to facilitate the optimal use of multi-sector data (Factor 3), and the last one focuses on the consistency and quality of data across sectors (Factor 4).

For this research, it should be noted that the analysis is less concerned with the distribution of participants than the general pattern of opinions that emerges. The strength of the Q-methodology lies in revealing the dominant patterns and opinions that emerge within a group.

5.7.5. Recommendations and Scaling up.

In light of these results, I propose a series of recommendations for the adoption and scaling-up of the proposed Model and the Triple Nexus Framework. To this end, this Section sets out a strategic and operational roadmap to identify the conditions and requirements for their adaptability and applicability.

From a strategic point of view, I recommend structuring the human settlement development organization and processes in line with UNHCR's requirements and reconciling the Model with the master planning approach as an improved and complementary guideline. In addition, follow-up work will need to align the composite indicators of the Nexus Framework with UNHCR indicators and standards for the water, energy and shelter sectors, as well as with key performance indicators.

Finally, to put this framework into practice, I will need to develop Standard Operating Procedures (SOPs) that will serve as a blueprint for the successful systematization of the internal

process framework in a unified and consistent way. These SOPs will provide clear guidelines and detailed instructions for the execution of specific tasks or operations in a consistent and efficient manner in order to achieve uniform implementation, reduce communication gaps and meet regulatory standards [109]. The proposed standard operating procedures will document how tasks are to be performed in order to facilitate consistent compliance with technical and quality system requirements, and to support data quality. Essential programmatic tasks and technical actions are the processes of analysis, maintenance, calibration and use of operational data. This will maintain the required quality control processes, ensuring compliance with UNHCR standards and government regulations.

From an operational point of view, technical activities will include engineering requirements, capacity analysis and data orchestration to transform the Nexus framework into a context- and operational data-driven system useful for planning and advocacy. In this respect, it is recommended to organize application tests in a few existing humanitarian contexts responding to the three situations: the emergency phase, the transition phase and the stability phase (prolonged and/or development). Secondly, a cost-benefit analysis will be carried out in comparison with the costs of parallel implementation of sectoral programs in the fields of water, energy and shelter in the medium and long term.

Furthermore, adoption of the Nexus framework is largely dependent on strategic decision-making and strong stakeholder commitment. As senior management recognized the importance of the Model and the TNF during the interviews, the follow-up work will be to develop an advocacy plan that will align with strategic planning cycles such as the annual strategic planning workshops.

5.7.6. Chapter Summary

To answer research question 2, I conducted an analysis and identified significant gaps in UNHCR's current approaches to developing more integrated and efficient centralized humanitarian settlements in terms of operational data management, and highlighted the significant benefits that MBSE methodology could bring to the planning and sustainable development of a humanitarian-scale human settlement. The answer to this question was provided by research tasks resulting from the application of MBSE methods and solutions to knowledge gaps, conceptualizing the integrated human settlement system and the triple Nexus, which was then modeled to enable a systematic and integrated view of the system. Concretely, tasks related to this research question using MBSE and SysML methodology resulted in the development of a Triple Nexus framework derived from the Urban Planning subsystem and focused on data processing and capacity integration perspectives.

A review of the literature on human settlements and the Nexus approach revealed that many studies, approaches and initiatives in this field had gaps and sometimes divergent viewpoints, and lacked effective, integrative visions. Modeling complex systems such as sustainable human settlements can be laborious in practice, particularly in humanitarian contexts. However, the MBSE method supported by SysML, a graphical modeling language, has proven capable of doing so and can be well applied to such contexts.

In response to Research Question 2, Tasks 2 and 3 developed the initial requirements diagram for the integrated human settlement system modeled. These were the most relevant requirements for initiating model design and system analysis. The resulting integrated human settlement system model reinforced the links in the system architecture and the resulting capability analyses.

In addition to the analysis of the capacity-constrained system and real-time data processing via a single integrated data platform, the two proposed scenarios aimed to test the behavior of the proposed Model in the real context in order to meet established requirements and verify the interaction between the various subsystems and components of the system, as well as to check how the system reacts when subjected to particular events commonly encountered in these specific contexts.

The integrated model made it possible to combine data from all subsystems on an integrated data platform that supports multiple use cases. While UNHCR's current approaches to humanitarian settlement planning and management, and in terms of operational data flows, continue to show decentralization and a lack of integration, the new approach developed in response to this research question is likely to be suitable as it focuses on modeling a human settlement system with all its interdependent, connected and integrated subsystems, and capable of automatically processing operational data, unlike existing approaches. The results of the system modeling demonstrate the relevance of building a new framework to integrate the Triple Nexus of water, energy and housing as the basis of a generalizable framework for the efficient application of composite and interdependent data across all sectors. The Triple Nexus is defined and designed as a framework for building and emphasizing the importance of creating and using composite indicators to prioritize more integrated, optimal, multi-sectoral and sustainable planning and management of human settlements.

Interviews conducted with practitioners and decision-makers to evaluate and validate the Triple Nexus Framework led to a consensus that the Water-Energy-Housing (WEH) Nexus Framework introduces a new perspective on the integration of essential resources and streamlines data processing across the three sectors, representing an important solution to address the

challenges of delivering standard quality services in these areas. Efforts to achieve sustainability under these SDGs goals 6, 7 and 11 have always been difficult. Finally, to better understand the importance of effective integration of subsystems and operational data flow, Chapter 6 uses a cross-impact assessment analysis to demonstrate the benefits of an integrated human settlement modeled using the MBSE methodology.

CHAPTER SIX - CASE STUDY: SYSTEM SUSTAINABILITY ANALYSIS THROUGH
CAPACITY ASSESSMENT AND MATRIX OF CROSSED IMPACT MULTIPLICATION
APPLIED TO A CLASSIFICATION (MICMAC) ANALYSIS

6.1. Sustainability Perspective in Human Settlement System

To answer Research Question 3, Chapter 6 evaluate the system's capabilities to process multi-sectoral data and sustainably deliver specific services that produce long-term sustainable benefits. This is achieved through a case study that focuses on the structural analysis of key factors and the role of each component and subsystem in the sustainability performance of an existing settlement in Kenya, and formulates a sustainability strategy using the MICMAC sustainability analysis Tool. The case study tests and validates the functionality of the system and its potential adaptation to UNHCR operations. This work assesses the capabilities of the integrated human settlement system to reach a certain threshold of sustainability in the delivery of specific services required by the six subsystems. For the system stakeholders, the goal of integrating the system would guarantee its sustainability and optimal lifespan if, and only if, the capabilities of its subsystems enabled the satisfactory achievement of specifically defined objectives over time. The integration of the system as a whole cannot function sustainably if the system is unable to achieve the agreed sustainable objectives. In this research, the sustainability of the integrated settlement system is analyzed from a system point of view, and the sustainability of the system is represented by the capacities of the subsystems to deliver results of interest to the population [99]. To this end, capacity assessment and MICMAC analysis are essential to answer Research Question 3 formulated as follows:

6.2. Research Question 3 - To what extent does the system capacity affect the overall system sustainability over time?

This research answers the question through a case study by conducting a System Capacity Interdependence Analysis (SCIA) using the MICMAC methodology to assess the interdependencies between the six categories of sub-systems.

In summary, the answer to Research Question 3 applies a more in-depth assessment of the system's capability to deliver sustainable services, to test how the interrelations of the subsystems are formulated, using the applicable MICMAC methodology.

6.2.1. System Sustainability Concept

A literature review reveals that, from an economic perspective, sustainability can be defined as the achievement of equity and balance between generations and a constraint on economic growth. According to Hackett [110], environmental ecologists argue that a sustainable society is based on the integrity of the ecosystem in which they live, and the ability to transform natural capital with man-made capital. In light of these views, sustainability can be understood as a process of generating and sharing meaningful data and information needed for sustainable decision-making that could contribute to the empowerment of people, the provision of environmentally friendly services and security, as well as broader employment opportunities in the long term. Another view from Læssøe J. [111], sustainability implies equitable governance of resources and a series of transformative processes that protect the environment and preserve ecology and well-being in various domains that are integrated, interdependent, and mutually influence each other, including urban planning, social services, economics and finance, good governance, ecology, and the environment.

For this research, the concept of sustainability is defined as the capacity of the system to achieve high performance sustainability outcomes when the system is designed in an integrated form and meaningful data is generated and enables it.

6.2.2. System Capacity Concept

The concept of capacity lies at the heart of the human settlement system, and is defined as the ability of different system components and stakeholders to achieve specific goals and satisfy requirements. As noted by Lavergne and Saxby [112], capacity can take many forms, tangible ones, such as infrastructures and institutions, and less tangible ones, such as skills, the social fabric, values and motivations, habits, attitudes, tradition, culture and so on. This research aims to demonstrate the ability of the settlement system and its subsystems to produce data and deliver satisfactory services over time. It defines the general state of settlement capacity, its multiple patterns of behavior and its structural components.

7.2.3. Study Area - Kalobeyei Integrated Settlement

The study area of this case study is the Kalobeyei integrated settlement, located in Kenya. This is one of the recent examples of UNHCR's attempt to transition from traditional planning approaches. According to the Settlement Advisory Development Plan [3], the settlement is being integrated and developed on 1,500 hectares of land in Kalobeyei town, Turkana West Sub-County, based on an agreement between UNHCR and the Government. This agreement was based on a commitment that the implementation would restructure humanitarian programming, emphasizing socio-economic integration, in an accessible, and functional settlement, complete with adequate social and physical infrastructure and a diversity of economic opportunities [87].

Based on the Kalobeyei Integrated Socio-Economic Development Plan (KISED P)¹¹, the settlement’s design framework is structured within eight complementary and mutually reinforcing components [87] which are closely aligned to some extent with the 17 Sustainable Development Goals (SDG) and with the six sub-systems of the new proposed Model. The eight programmatic components of the KISED P aligned with the SDGs are presented below.

KISED P and the SDGs	
KISED P Components	SDGs
Health	3, 6, 10
Education	1, 4, 5, 8, 10
Water, Sanitation and Hygiene	6
Protection	1, 5, 10, 16
Spatial Planning and Infrastructure	1, 11
Agriculture, Livestock and Natural Resources Management	1, 2, 12, 13, 14, 15
Sustainable Energy Solutions	7, 12, 13
Private Sector and Entrepreneurship	1, 8

Figure 42: KISED P eight complementary components (or subsystems)

Source: <https://www.unhcr.org/ke/kisedp-2>

Each component has its own sectoral objectives and indicators that directly contribute to one or more strategic objectives. As of 31 December 2023, the settlement hosted approximately

¹¹ The Kalobeyei Integrated Socio-Economic Development Plan (KISED P) was initially devised to support a new approach aimed at establishing a settlement in a place called Kalobeyei in Turkana West, where both refugees and host populations would live together, rather than a separate refugee camp. It provides a framework and tool to manage the presence of some 180,000 refugees (40% of the population of Turkana West) in a manner that is of benefit to both the refugees and their hosts.

38,000 refugees, including people from South Sudan, Ethiopia, Somalia, Burundi, and other countries, as well as members of the host community¹².

6.2.4. Sustainability in Kalobeyei Settlement

A recent study [113] revealed that the Kalobeyei settlement continues to face several challenges and threats with regard to achievements in sustainability or, more precisely, self-sufficiency. Betts A., Naohiko O. and Sterck Olivier, in a comparative study carried out in 2020, [114] examined refugee policies and the approach to humanitarian and development programs implemented in Kalobeyei and found that achievements in self-sufficiency, including factors aligned with sustainability, such as environment, assets, networks, markets and public goods, are provisioned unsatisfactorily. However, in reality, displaced populations in the settlement area continue to struggle with the lack of reliable energy, affordable housing, clean water and poor sanitary conditions, limited access to basic services, among others. The lack of large-scale and forward-looking self-reliance options and the complexities between vision and its implementation were also mentioned. Furthermore, the development of the conurbation seems to present an incompatible amalgam of a vision of development based on integration, mobility, and economic, to be achieved in a very restricted and economically challenging environment [115].

A household survey carried out in the settlement in October 2023 revealed that the water supply is insufficient to meet daily needs and required standards of at least 20 liters per person per day [103]. Although the KISED P's component five addresses land use and infrastructure development through its sub-component seven, the capacity to provide affordable housing remains one of major challenges. In terms of energy, the settlement still lacks reliable access to electricity. Only 5% of households have access to electricity, with firewood, charcoal and solar energy being

¹² Refugees and local residents' study, play and live together at Kalobeyei Integrated Refugee Settlement | UN-Habitat". unhabitat.org. Retrieved 2 December 2023.

the main means of lighting and cooking. The market for firewood is estimated at 12,046 metric tons per year and, together with charcoal, it is the main source of cooking fuel for 62.7% and 37.3% of households, respectively [116]¹³. There is evidence of growing demand for more comprehensive and system approach to explore possible synergies and trade-offs within the settlement, and to capture and assess the linkages between components that would trigger sustainable service delivery. For example, how would strengthening one form of capacity to achieve a specific goal such as the provision of a reliable service (e.g. water, energy, housing, etc.) affect the achievement of another goal associated with a different type of service from other sectors over time. Similarly, how does the interaction between different system-level components (e.g. institutional and governance, social, spatial planning and infrastructure, ecology and environment, economic and financial) and populations contribute to system sustainability over time?

For the sustainability assessment, I used a participatory method with semi-structured and in-depth interviews with Kalobeyei stakeholders and UNHCR field staff, and applied the sustainability analysis technique of Cross Impact Multiplication Matrix Applied to Classification (MICMAC) to identify key factors and elements of the settlement's sustainability that are essential to overcoming the challenges examined in this research.

6.2.5. Kalobeyei Settlement Programmatic Framework

According to the Kalobeyei settlement programmatic outline [3, 87], the planning, development and management of the settlement would be led by the County government and coordinated through eight thematic areas of intervention which include health; education; WASH;

¹³ From a study conducted by the Moving Energy Initiative (MEI) a partnership between Energy 4 Impact, Chatham House, Practical Action, the Norwegian Refugee Council and the UNHCR, on prices, products, and priorities of clean, safe and affordable energy in Kakuma refugee camp. Published on 14/02/2018.

protection; spatial planning & infrastructure development; agriculture, livestock and natural resources; sustainable energy solutions and private sector and entrepreneurship. The KISED P outlines the settlement programmatic framework as presented in Table 18, which provides the platform for information sharing, design, planning, development, implementation and monitoring mechanisms, which would strengthen the nexus approach, thereby ensuring the sustainable development of the settlement.

Table 18: Kalobeyi Settlement Programmatic Framework (Adapted from [87])

Thematic areas of interventions	Settlement requirements
<u>Steering Committee</u> : Government-led initiative	A steering committee to oversee and guide policy issues. The committee is co-chaired by the County Government and UNHCR. Members are representatives from the humanitarian community and NGOs.
<u>Component 1 to 3</u> : Sustainable Integrated Service Delivery & Skills Development (Health, Education, Water, Sanitation and Hygiene)	Supporting cost-effective and sustainable social services, including education, health, water, sanitation and hygiene, that will benefit host communities.
<u>Component 4</u> : Protection	Supporting systems and services consistent with the national legal framework through a comprehensive approach.
<u>Component 5</u> : Spatial Planning & Infrastructure	Facilitating spatial planning to guide area development approach and the transformation into sustainable urban areas.
<u>Component 6</u> : Agriculture, Livestock, and Natural Resources Management	Supporting the development of a commercially viable agricultural and livestock sector, as well as better management of natural resources.
<u>Component 7</u> : Sustainable Energy Solutions	Improving access to affordable, reliable, and renewable energy, to further stimulate opportunities for economic growth.
<u>Component 8</u> : Private Sector & Entrepreneurship	Promoting the private sector and entrepreneurship.

From a SE perspective, I proposed a strategic alignment with the logical structure developed in the new system Model. Table 19 presents the suggested structural alignment.

Table 19: Alignment Between Kalobeyei Settlement Components (Adapted from [87]) and the Proposed Integrated Human Settlement Model.

Integrated human settlement model Sub-systems	Potential alignment	Kalobeyei settlement components (or TWGs)
Sub-system: Institutional & Governance	↔	Steering Committee
Sub-system: Social & Basic Services	↔	<u>Component 1</u> : Health
		<u>Component 2</u> : Education
		<u>Component 3</u> : Water, Sanitation and Hygiene
Sub-system: Populations (displaced and host)	↔	Component Four: Protection
Sub-system: Urban Planning & Infrastructure	↔	<u>Component 5</u> : Spatial Planning & Infrastructure
Sub-system: Ecology & environment	↔	<u>Component 6</u> : Agriculture, Livestock, and Natural Resource Management
		<u>Component 7</u> : Sustainable Energy Solutions
Sub-system: Economy & Finance.	↔	<u>Component 8</u> : Private Sector & Entrepreneurship

6.2.6. Methodology and Tools

In terms of methodology, this research focuses on structural analysis of the eight components of the settlement and their alignment with the six subsystems of the proposed Integrated System Model, and the role of each component in the sustainability of the settlement. A modified version of the UVC framework, referred to as University of Virginia, Charlottesville (UVC) Capacity Analysis methodology is used to assess the system’s capacity and a qualitative approach with the MICMAC sustainability analysis technique, all together with observations, interviews and field surveys. The research instruments used to collect data are questionnaires, individual interviews and household surveys, and field observations conducted in the Kalobeyei settlement in October 2023 (CSU IRB Protocol #5005|V1). For interviews and surveys, respondents were selected based on their expertise and involvement in humanitarian operations.

6.2.6.1. Methodology Process

The Figure 43 summarizes the methodological process for the system capacity assessment.

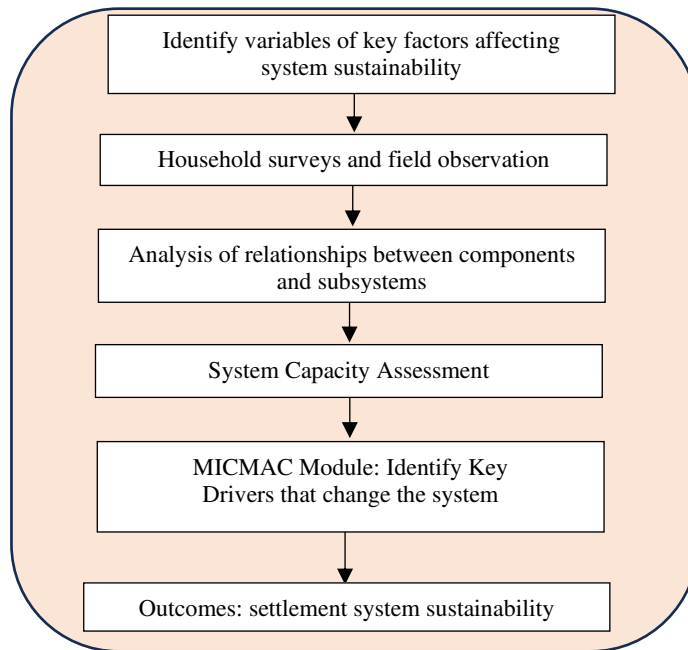


Figure 43: Sustainability Capacity Assessment Methodology Process

6.2.6.2. System Capacity Assessment

Capacity assessment is an evaluation task that aims to measure the potential of a community in given area to achieve specific goals. This Chapter applies a modified version of the framework referred to as UVC, developed by researchers at the University of Virginia [28, 48]. The UVC framework [117]¹⁴ considers eight categories of capacity involved in delivering services to the community at various levels and each category consists of several requirements (or constituents). These categories can be service level, institutional, human resources, technical

¹⁴ UVC Framework was developed by Professor Garrick Louis and coworkers at the University of Virginia, Charlottesville (Ahmad 2004; Bouabib 2004; Louis and Bouabib 2004) as a detailed methodology to determine the capacity of a developing community to conduct municipal sanitation services (MSS) projects. As remarked by Bouabib (2004), these services may include more complex systems. In general, the approach can be generalized to other types of projects and services besides MSS, such as education, health, energy, or food, as discussed by Faeh et al. (2004).

resources, economic and finances, energy, environmental, and social and cultural. For each capacity category, a capacity factor is calculated as the weighted sum of its requirement scores [117]. The UVC framework was designed to assess the capacity of small communities to manage the provision of local municipal services and that it could be generalized in similar contexts and conditions to analyze the capacity of service delivery in the human settlement system, provided that the characteristics of the eight capacity categories correspond to the six defined subsystems. I examine the six subsystems and their correspondences with the eight components of the Kalobeyei settlement (Table 10). To account for the interdependencies that exist between the different capacity categories, I apply the modified UVC framework with the six capacity categories. All categories are assumed to be interconnected and contribute to the overall capacity to process meaningful data and services at a specific scale in the settlement. Figure 58 shows an adaptation of the framework that considers the six sub-systems of the system aligned with the KISED P.

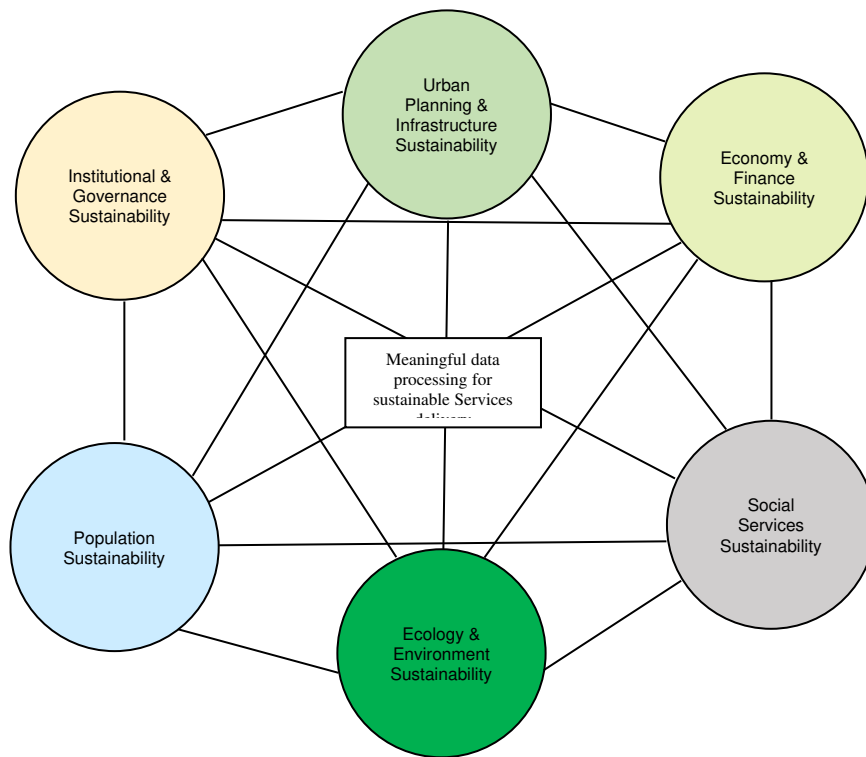


Figure 44: Representation of the Six Categories Interconnected Subsystems Focused on Data and Service (Adapted from [87]).

In application of the modified UVC framework, to account for the six system's requirements in the determination of the system Capacity Assessment (CaA), a (X_i , $i=1-6$) requirements need to be met for each category of capacity as per Figure 44. Based on the weakest link criterion as recommended by Bouabid [117], the system Capacity Assessment Ca_A is determined by a formula that accounts for the various feedback mechanisms among the different categories of capacity stated as follows:

$$Ca_A = \text{Min} (CaFt_i ; i = 1 - 6) \quad (1)$$

And each capacity factor $CaFt_i$ ($i = 1-6$) is equal to

$$CaFt_i = \sum_{j=1}^{N_i} Ca_{ij} w_{ij} \quad (2)$$

where Ca_{ij} and w_{ij} ($j=1-X_i$) represent the requirements scores and weights associated with the i th capacity factor $CaFt_i$ ($i=1-6$) respectively. Each capacity factor $CaFt_i$ in eq. (1) is assumed to depend somehow on the other six ($CaFt_k$, $k \neq i$). Likewise, in eq. (2) each requirement score Ca_{ij} is assumed to depend on all other possible requirement scores (Ca_{kl} , $k \neq i$, $l \neq j$).

Considering the Kalobeyei settlement as the study area, I identified the types of capacity and their requirements in processing operational data and delivering all types of services, as listed in Table 20.

Table 20: Capacity Types and Requirements (Adapted from [87]).

Combined Capacity types	System sustainability description	Kalobeyei settlement requirements
Institutional & Governance (Steering Committee)	Advocating for policies and laws, promoting strong institutional models, good governance, transparent and partnerships.	Oversight and guidance on policy issues. Data and information are key

Social Services delivery (health, education, energy, water, housing)	Ensuring the delivery of integrated and sustainable social services.	Supports cost-effective and sustainable social services,
Populations	Workforce to develop services and capacity building.	Supports systems and services in line with legal framework.
Urban Planning & Infrastructure (Spatial planning & infrastructure development).	Sustainable urban and spatial development, including technical network and infrastructure.	Facilitates spatial planning to guide the area's development and necessary urban transformations.
Ecology & Environment (agriculture, livestock, and natural resource management)	Streamlines climate action and environment, land use and natural resources management.	Supports viable agriculture and livestock and improved natural resource plans.
Economy & Finance (private sector & entrepreneurship)	Partnerships for local economic growth and financing, entrepreneurship, and self-reliance.	Supports development of private sector and entrepreneurship.

6.2.6.3. Matrix of Crossed Impact Multiplication Applied to a Classification Analysis

The MICMAC methodology is used for the system sustainability analysis. It was developed by Godet [118] and applied in sustainable development analyses by (for example) Fauzi A. [119 , 120]. This method was also used in [121] to conduct Small-scale Vannamei shrimp farm business sustainability analysis. It was also applied by Amadei B. [122] in his work to study a capacity assessment for a small village in Morocco. As applied by Fauzi, the MICMAC process begins with the problem definition, identification of variables, analysis of relationships between variables and weighing of dependences [123].

As a suitable method for sustainability analysis, I applied the MICMAC according to the methodology process (Figure 43). The first step of MICMAC analysis is to identify the key factors affecting the sustainability in the Kalobeyei settlement. Then, a structural analysis of inter-variable interactions of subsystems as drivers for sustainability service delivery.

6.2.6.4. Cross-Impact Analysis

Cross-impact analysis, also called dual causality analysis, is a mathematical methodology developed by Gordon and Helmer [124] to investigate how relationships between events could impact the resulting events and reduce uncertainty in the future. Different cross-impact analysis formulations differ in how the interrelations of the system components are formulated (probabilistically or deterministically) and whether a qualitative, quantitative, or mixed approach is used to describe causalities [117]. Cross-impact analysis is used to map and analyze how the six capacity categories influence and depend on each other.

For the settlement system composed of x interacting variables, the cross-impact analysis is represented by a $(x \times x)$ cross-impact matrix with zero diagonal terms and $x^2 - x$ off-diagonal terms [117, 122]. The off-diagonal terms define the double causality between the x interacting variables, how each variable or row directly influences or impacts the other variables, and how each variable or column depends on or is sensitive to the other variables. The cross-impact matrix is also referred to as the matrix of direct influence (MDI) by Godet [118] and is not necessarily symmetric as shown in the Table 21.

In October 2023, a data collection survey [125]¹⁵ was conducted in Kalobeyei refugee settlement and Kakuma refugee camp in Kenya. A group of twenty refugee households and community representatives were interviewed by informants from the UNHCR office in Kakuma. The answers provided by each group were recorded and scored on the questionnaire templates used by the interviewers. The subsequent analysis of the scores, brainstorming and consensus-

¹⁵ Kalobeyei settlement and Kakuma camp surveys on access to water, energy, and shelter result analysis. [Available at: [Kalobeyei Responses on Shelter, Water and Energy.pdf](#)].

building among members of the refugee community resulted in the scores indicated for each of the 30 off-diagonal terms of the double causality matrix in Table 21.

Accordingly, Table 21 presents 6 x 6 variables to be the Matrix Direct Influence (MDI) for the capacity considered in Figure 44. The off-diagonal of the MDI represents the possible feedback mechanisms and interlinkages that exist when two categories of capacity interact interdependently. Influences range from 0 to 3, with the possibility of identifying potential influences: 0: No influence; 1: Weak; 2: Moderate influence; 3: Strong influence. Based on the results of the interviews conducted in Kalobeyei settlement, the scores have been retained and used for analysis.

Table 21: Matrix Direct Influence (MDI) for Kalobeyei Settlement Sustainability Analysis

	1. Inst/Gov .	2. Populations	3. Urban Plan / Infrast.	4. Soc/Services	5. Eco/Fin.	6. Env/Ecolo.	Net Influence
1. Inst/Gov.	0	3	2	2	1	2	10
2. Populations	3	0	1	2	1	1	8
3. Urban Plan / Infrast.	1	2	0	3	3	3	12
4. Soc/Services	1	2	3	0	2	2	10
5. Eco/Fin	2	2	2	0	0	3	9
6. Env/Ecolo.	1	2	3	2	1	0	9
Net Dependence	8	11	11	9	8	11	58
Average Dependence	1.33	1.83	1.83	1.5	1.33	1.83	9.65

Based on the MICMAC methodology, Table 21 is used to determine each capability category's net direct influence (impact) on the other five and the net direct dependence (sensitivity) of each capability type on the other five. The scores are summed by rows and columns, respectively. The net influence values represent how each capability category affects the system as a whole, while the net dependence values represent the effect of the system on each capability type. To

facilitate analysis, the Direct Influence/Dependence diagram is generated by plotting the degree of dependence and influence values on a single graph of influence (x) versus dependence (y), as shown in Figure 45. The average value of direct influence and dependency for all domains is 9.65. According to Godet [118], and following the pattern formed by the Direct Influence/Dependence diagram, the capability categories can be separated into four quadrants. These four quadrants are as follows:

- *Influential variables* (Quadrant I) with high influence and low dependence.
- *Excluded variables* (Quadrant II) with low influence and dependence.
- *Relay variables* (Quadrant III) with high influence and dependence.
- *Dependent variables* (Quadrant IV) with low influence and high dependence.

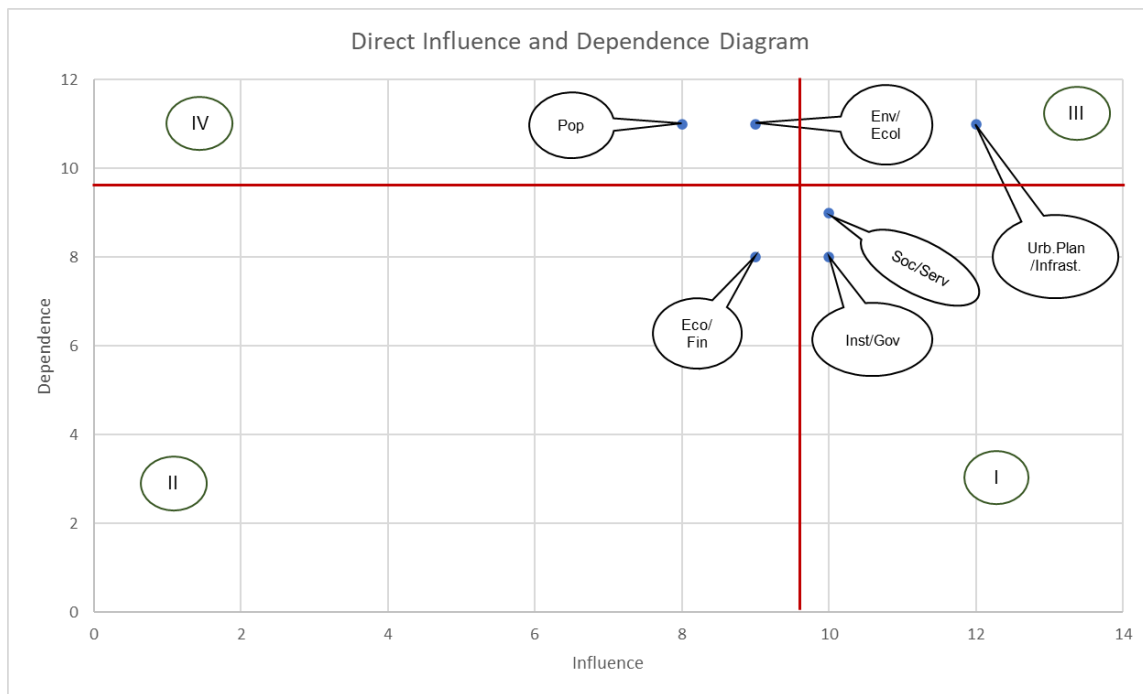


Figure 45: Sustainability Variables Diagram by Influence and Dependence

The abbreviations shown in Figure 45 are described as follows:

Pop = Settlement populations; **Eco/Fin** = Economic and Finance; **Env/Ecol** = Environment and Ecology; **Soc/Serv** = Sociaux services; **Inst/Gov** = Institution and governance; **Urb Plan/Infrast.** = Urban planning and Infrastructure.

6.2.6.5. Results Analysis

Figure 45 presents the influence and dependence diagram highlighting the system capacity to deliver sustainable services. It is apparent that the Institutional Capacity and Social Services delivery capacity fall in Quadrant I with high influence and low dependence. Quadrant I falls in the influential variables demonstrating that these two systems' capacities have higher leverage and dominance among all types of capacity in the system. Previous studies [126, 127, 128, 129] also reveal similar results because of the full engagement of the Kenya government and local leadership in the settlement development and that the refugee populations and their hosts were to rely on traditional humanitarian assistance to cover their immediate social and basic needs (food, housing, and health care) [126]. The Economy and Finance capacity falls in Quadrant II, which falls in the *excluded variables*, constituting the low influence and dependence. This capacity is categorized into factors that reflect the system instability as revealed in the Felleson's [186] study on the KISED P published in February 2023. According to [129], since the launch of the KISED P in 2018, the implementation has only been partial and as stated in a recent official report [126, 127], '*the funding requirement for July 2019 to June 2021 was USD 217.9 million of which only USD 127.4 million was received, and partners purported to have only received 43% of their budgeted funds*'. The report states that '*.....more effort will be required to strengthen resource mobilization and advocacy with potential donors and through new prospective partners, including the private sector, to ensure the success of the settlement development Program and the need for the planned objectives. Gaps in funding will negatively impact on KISED P's implementation and risk delaying progress in Turkana West achieving self-reliance and socio-economic development*'. Consequently, any improvement in the Economic and Finance capacity may cause relatively important effects on the other variables and on the system at large in achieving the sustainability

goals. On the other hand, Urban Planning and Infrastructure Development capacity is in Quadrant III, which falls in the relay variables group, constituting the influencing variable but with high dependence. This capacity presents more challenging to address since its influence and dependence cannot be separated through feedback mechanisms. The challenging state of this capacity can be understood through the study [129] which pointed out the undisputed fact that the geographical conditions of the settlement's location present challenges for the best suitable urban planning and infrastructure development at this time. More than 80% of the Turkana County is categorized as either arid or very arid and rain patterns and distributions are erratic. The settlement's location is within the latter category, presenting close to desert-like conditions. Therefore, a strategy focused on Urban Planning, access to critical services and infrastructure, including agricultural production as a basis for self-sufficiency must, in the first instance, find innovative and sustainable solutions to the critical issue of access to water. More importantly, a recent report from the UN-Habitat [128] provides similar arguments highlighting several challenging circumstances facing the Kalobeyei settlement such as natural hazard vulnerability, insufficient infrastructure and facility provision, and very limited employment opportunities.

Finally, the capacity of Populations and Environment are located Quadrant IV, of which conditions reflect the *Dependent variables* with low influence and high dependence. These subordinate domains are "strong indicators of the 'health' of the entire system of variables. Despite the low influence of these capacities, this nevertheless demonstrates the preponderance of people's dependence on the environment and ecosystem in which they depend, and the weakness of their influence may be a signal of their lack of real participation in settlement governance and, thus, in decision-making processes, including in other capacities. It is evident that most of the population is largely dependent on aid, as also noted in the reports [128, 129] that brought to the fore the

intimate relationship between aid and economic development: ‘Without the aid system, most businesses in Kalobeyei settlement would collapse’.

In conclusion, the results of the sustainability analysis, based on the pattern formed from the inner quadrant system presented in Figure 59 of sustainability variables by influence and dependence and according to Godet, the development activities of the subsystems of the Kalobeyei settlement is unstable and therefore unsustainable since there is no clear difference between the influential variable and the dependent variable.

6.3. Chapter Summary

Chapter 6 sought to answer the third Research Question (RQ3), which was to investigate how different levels of system capacity could influence the sustainability of the settlement system as a whole over time. This Chapter demonstrated, through a case study, the sustainability analysis of the settlement system in Kenya using the MICMAC qualitative approach. This work applied the systems approach adapted from UVC's capability analysis framework, which uses different categories of capability to analyze the provision of one or more services. The case study analyzed the sustainability of the settlement system and assessed the capacity to reach a certain threshold of sustainability. The results showed that the current level of subsystem development activities in the settlement is unstable and, therefore, unsustainable since there is no clear difference between the influential and dependent variables. There is therefore a need to simultaneously improve the current capacity of the settlement in all subsystems and plan for their long-term sustainability. The challenge is to develop an action plan for sustainability at different scales. For this research, the sustainability of the settlement was analyzed from a systemic perspective and was represented by a non-decreasing evaluation function to deliver specific services.

The sustainability of a typical human settlement is not static, as it evolves over time. Understanding the capacity of subsystems and their variations over time allows decision-makers and practitioners to implement solutions and strategies that are adapted to current conditions. This action plan or strategy to ensure the overall sustainability of the settlement management will be part of future work. Regardless of scale and context, the systems engineering approach applied in humanitarian operations requires a detailed assessment of the sustainability capacities of the settlement to be effective. Furthermore, decision-makers and practitioners involved in human settlement development must be prepared to adopt new systems engineering mindset from the outset of planning, design, and implementation, and to work in partnership with other stakeholders.

CHAPTER SEVEN: RESEARCH CONTRIBUTIONS AND CONCLUSIONS

7.1. Research Contributions

In line with the research objectives, the research contributions to the proposed new Human Settlement System model and Triple Nexus Framework include an application of fundamental Systems Engineering methods in humanitarian operations to improve planning and decision-making to better serve displaced people.

This research attempts to address a critical and contemporary issues related to improving the living conditions of displaced populations in sustainable human settlements. It introduces a novel approach using the advantages offered by SE, MBSE and SysML, presenting an innovative methodology in the context of humanitarian efforts, which is relatively unexplored in current literature. The research also addresses an important global challenge, contributing valuable insights towards sustainable solutions for displaced populations, aligning with the UN 2030 Agenda for Sustainable Development [130, 131, 132, 133]. The focus on MBSE to streamline data processing across the water, energy, and housing sectors represents a significant step forward in optimizing humanitarian operations. Furthermore, the research provides a comprehensive analysis of the challenges facing the sustainability of humanitarian settlements and proposes a new methodology for developing models of sustainable human settlement systems, with important theoretical and practical implications.

More specifically, research contributions are the following:

1. A novel and first-documented example of application of SE and MBSE in a humanitarian context. Sustainable human settlements are considered an ongoing concern of international humanitarian policy, and attempts are currently being scaled up to make transitions in response

to the challenges faced by humanitarian actors. Given that there is as yet no single, accepted definition in the literature, but rather from specific perspectives, I conducted an analysis of existing definitions of the concept of integrated, sustainable human settlement, in order to deepen understanding and shed further light by defining a new concept for this research. Using the Systems Engineering Modeling Language (SysML), I developed a Model of an integrated settlement system, which was tested for the first time in such a context with specific scenarios.

2. This research is innovative in that it considers the concept of human settlement from a system perspective, in which the six integrated subsystems operate together and interact interdependently. This has resulted in more efficient and reliable management of operational data to solve the identified problems, I designed and applied a new decision support method and reached a consensus on system data management and decision sharing through a Triple Nexus Framework decision support model.
3. This research resulted in the architecting and modeling of a framework for processing sectoral data, integrating data into a unified platform that serves as a gateway for the formulation of composite and multi-sector indicators widely demanded in today's humanitarian and development world. The novel Framework is documented by a survey as a significant improvement to UNHCR's current practices and methods and will generate substantial savings in terms of financial, human and time resources. The novel Nexus Framework model was widely endorsed by stakeholders interviewed as a positive and significant contribution to strengthening UNHCR's reform efforts in terms of aligning and structuring sectors, resources, and operational databases, which will improve the performance of humanitarian programs.
4. Finally, the proposed decision support framework represents a major innovation in facilitating decision-making and governance processes within UNHCR's multifunctional teams. The

roadmap I recommended presents programmatic and operational changes aimed at improving the functioning of multifunctional efforts. Finally, the case study demonstrated that achieving an acceptable threshold of human settlement sustainability is possible, though the concept is dynamic as it evolves over time.

5. The capacity assessment conducted serves to illustrate that systematic integration of a human settlement system is not enough to achieve overall sustainability at scale, but requires more capacities across the system to deliver services the required services.

These contributions and supporting research for this work are published in the following key delivered products and peer-reviewed publications:

1. Adjahossou A. *Framework for Applying Sustainability Principles in Humanitarian Shelter Cluster Operations Through Systems Engineering Approach*. Presentation at UNHCR Annual Shelter Cluster Retraite, 2023 [134].
2. Adjahossou A. (2024). *Model-Based Systems Engineering Approach to Design a Human Settlement to Better Serve Displaced People*. Journal Scientific Research, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132350>].
3. Adjahossou A. (2024). *A Systems Approach to Assessing Sustainability Capacity in Kalobeyei Refugee Settlement in Kenya*. Journal Scientific Research, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132425>].
4. Adjahossou A. (2024). *A Triple Nexus Water-Energy-Housing (WEH) Framework Modelling Towards Improved Decision-Making in Humanitarian Operations*. Journal Scientific Research, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132447>]

7.2. Research Conclusions

7.2.1. Dissertation Summary

The fundamental objective of this research was to deepen the understanding of human settlement as a system and to attempt to define the concept of integrated sustainable human settlement applicable in humanitarian contexts. To highlight this perspective, I demonstrated that human settlements face several shortcomings and challenges generated by a number of factors, such as a growth in displaced populations combined with rapid urbanization, but also raise other problems in the processing of operational data, which occurs in an incongruous, dispersed and decentralized manner, hampering the achievement of the minimum standards required on a sustainable basis.

For this research, various issues facing contemporary humanitarian settlements and motivating the transition to sustainable human settlements were highlighted. In light of this, this research demonstrated that the concept of integrated human settlement can be considered the best solution to many of these shortcomings and challenges. Some definitions were reviewed, which enabled to define the concept in the context of this research. Thus, to effectively achieve an integrated and sustainable human settlement, I demonstrated that it must be viewed and approached as a system comprising six subsystems functioning together as interdependent and integrated elements. However, UNHCR's attempts to transition towards sustainable settlements have instead produced disconnected and non-integrated systems due to the high complexity of the humanitarian settlement system and the diversity of stakeholders involved. To address these shortcomings in the face of such complexities, Systems Engineering was identified as a best-suited approach to cope with the transition processes. SE approach was described using the MBSE methodology and SysML. No Magic's Cameo Systems Modeler, a model-based systems software

that enables the creation, collaboration, and management of system requirements and designs, was applied to model the system, making all subsystems interrelated and integrated. Upon this basis, I developed an initial conceptual model of the typical human settlement system and then expanded the structure and behavior diagrams into a holistic and integrated model. The proposed integrated human settlement model was presented and validated through structured individual interviews and Q-Statements analysis with UNHCR staff and experts in the research field. The results revealed a consensus on the added value of such a new Model, which strengthened the interconnections within the architecture of the human settlement system and demonstrated that the methodology developed could provide a valid solution to the complexities at stake in the current humanitarian settlement planning and management processes. To demonstrate the functionality, the proposed Model was simulated through two scenarios that tested the interactions of elements and verified how the system reacts when subjected to specific extreme events.

With regard to the shortcomings observed in the processing of operational data from the water, energy and housing sectors within a multi-sectoral approach, a Triple Nexus decision support framework is proposed to identify opportunities for analyzing and processing multi-sectoral, composite and integrated data from these three sectors, as well as recommended improvements in the performance of their processing through a single and simplified integrated data platform. The Triple Nexus Framework as a decision-support tool was evaluated during interviews with data managers.

The sustainability of the system model was assessed using a case study to determine the capacity of an existing settlement system to reach a certain sustainability threshold. The results showed that the current level of development activity is unstable, and recommended the need to

simultaneously improve the system capacities in all sub-systems and plan for their long-term sustainability.

7.2.2. Chapter Summaries

Chapter 1 provides an overview of human settlement, including the status of the current approach implemented and access to basic services such as water, energy and housing. The first chapter outlines the main challenges associated with the transition to more integrated and sustainable human settlement and describes the underlying root causes, which are largely attributable to the substantial increase in the number of forcibly displaced people over recent decades, the difficulties in providing basic services on a sustainable basis and the protracted nature of emergencies. A research approach is proposed based on MBSE and SysML, to illustrate the architecture and behaviour of the system with six subsystems showing how an integrated data platform can serve as a gateway to facilitate access to the data stakeholders need

Chapter 2 presents the research questions and associated tasks addressed by this research. The first research question addresses the current state of the approach to humanitarian settlement data management, exploring the key challenges, gaps and potential benefits that SE could bring to humanitarian settlement planning and and data management. The result is the identification of knowledge gaps and the definition of the concept of sustainable integrated human settlement. It also analyses the state of the art in this field, classifies SE methods applicable to the design of integrated human settlement systems, and defines the Triple Nexus Framework and decision support model. Finally, recommendations are made to facilitate operational data processing and decision making.

The second research question examines and adopts MBSE and SysML methodologies for the design of the integrated human settlement system and the Triple Nexus Framework in UNHCR operational contexts.

Chapter 3 defines the integrated human settlement system concept from an operational data management perspective, based on the literature review, and examines current approaches to integrated human settlement planning within UNHCR guidelines. The result provides a basis for understanding the organization, functions, and attributes of an integrated human settlement, as well as aspects of SE that could be applied for effective and beneficial data processing in the planning and management of a human settlement system.

Chapter 4 generates a standard platform modeling methodology and provides a visual semantic representation. It presents a Model of an Integrated Human Settlement System that would address related issues such as data flow processing, interoperability and scalability. It then explores the complexities of human settlement in the face of the current approach that produces disconnected systems, where subsystems are neither interconnected nor integrated, and describes how the MBSE approach is reactive in that it functions as a system. In addition, this chapter introduces the initial concept of an Integrated Human Settlement System and the Triple Nexus Framework.

Chapter 5 develops the Integrated Human Settlement System model and the Triple Nexus Framework, focusing on data processing and capacity integration perspectives. This chapter proposes two scenarios to test the system's behavior in relation to requirements, checking the interactions between the system's various subsystems and how the system reacts when subjected to particular events often extreme events to prove the system's capacity and performance. This chapter also describes the structured interview processes and presents the results obtained, which

led to a consensus on the acceptability of the Model and the Triple Nexus Framework in the context of UNHCR operations.

Finally, to better understand the relevance of subsystem integration and efficient data flow in ensuring system sustainability, Chapter 6 applies a cross-impact assessment analysis to demonstrate the many advantages of the Model in effectively achieving certain sustainability thresholds using the MBSE methodology through a case study.

Chapter 7 describes the research contributions and findings and provides a list of supporting publications. In line with the research objectives, contributions include the successful application of Systems Engineering in humanitarian operations to improve planning and decision-making to better serve displaced people. Publications resulting from this research include journal articles, presentations and other technical tools developed to support some of UNHCR's ongoing human settlement development projects in the field.

7.3. Future work

Future work related to this research can be classified according to the importance of extending the understanding system model into humanitarian operations.

Firstly, the interviews showed that the Model should not be too academic. To make it more practical, understandable and easily assimilated by the senior managers and directors who are the decision-makers, future work would involve integrating MBSE and SysML with other tools, such as MatLab, or other more "accessible" or "free" applications to perform co-simulation and further analysis and validation of the Model and the TNF. It should be noted that SysML has its limitations, and that co-simulation would enable modeling complex dynamic systems to be modeled using other advanced engineering analysis tools. This would certainly bring new challenges concerning the behavior, management and simulation of a unified, integrated model of

a human settlement system that would be more widely adaptable and applicable on a large scale. In order to ensure stable operation of the proposed Model and to enlighten stakeholders on the concept of sustainable integrated human settlement as a complex system, and on how to holistically transform contemporary urban systems, further studies could be undertaken in the future. In this case, the proposed Model could be subjected to a series of robust simulations based on more demanding and realistic scenarios, while focusing on the interactions and integration of all subsystems at once, in order to highlight the added value of integration capacities that meet the requirements.

Further future work would involve detailing the MBSE methodology described for the integration of a sustainable human settlement system, focusing on the internal structure and architecture to facilitate the full integration of sustainability criteria (beyond capacity measures alone) by deepening the understanding of the Model's internal structure and behavior.

Given the shortcomings in the areas of operational data processing, this research developed an integrated SE methodology. Future work would consider other possible perspectives for testing and validating the proposed integrated system Model and the Nexus Framework. For the decision support Triple Nexus Framework, it is envisaged to extend the integration to other subsystems in order to increase the composite indicators, thereby increasing the effectiveness and scope of the TNF. This future work would involve the integration of other SDG indicators to establish a stronger interdependence and transition between humanitarian and development, as also suggested during the interviews.

By applying the TNF to the processing and management of operational data, functionality improvements for specific tasks will be identified. Their impacts on overall system performance will help measure the success of the Framework's implementation. With regard to the extensibility

of the TNF, and to facilitate its application to other systems or operational domains, it is envisaged to adapt it to other accessible and usable applications, such as MatLab, Excel, etc. Further work would be carried out to establish linkages between the system's integrated data platform and other existing UNHCR databases, and to develop specific standard operating procedures to strengthen current systems and internal capacities.

The case study revealed that much work remains to be done to achieve a mature system using a wider range of real-time data and involving a complete set of the systems's subsystems. Therefore, future work in this area would consider broader data from the other real-time subsystems to make system testing and validation more accurate and reliable. Furthermore, the methodology applied in Chapter 6 considers only one type of capacity or service at a time. In complex situations, where several interdependent capacity types need to be provided to the system simultaneously, the system capacity assessment should first be determined for each type, taking into account the different forms of influence and dependency between the system capacity categories. Thus, the management of one type of capacity may have direct or indirect consequences on the provision of another, and requires trade-offs. One may choose to prioritize water resources for energy production over those for housing, or vice versa. To take into account all the linkages in the provision of multiple services at system level, an analysis of system dynamics would be relevant to determine the feedback that would enable system stakeholders and policy makers to adopt advanced system-based decision-making. Finally, to contribute to the dissemination of this research within UNHCR operations, I foresee a series of applications in several humanitarian operations in order to increase the scope of consensus on its applicability and adaptability, and ultimately recommend it as a new Model and operational Framework complementing the ten guiding principles for settlement planning.

REFERENCES

1. United Nations High Commissioner for Refugees (UNHCR) Global Appeal 2023. [Available from: <https://reporting.unhcr.org/globalappeal-2023>].
2. Arroyo C. M. (2017). *Rethinking Refugee Camp Design: From 'Temporary' Camps to sustainable settlements*, Nasr Chamma Universitat Internacional de Catalunya, Spain. Universitat Internacional de Catalunya, Spain, June 2017.
3. UN-Habitat (2016). *Kalobeyei Settlement Advisory Development Plan (2016-2026)*. [Available at: <https://unhabitat.org/kalobeyei-settlement-advisory-development-plan-turkana-county-kenya-final-draft>].
4. Muvuna. J. *Systems Engineering Approach to Design and Modelling of Smart Cities*. Glasgow Caledonian University – October 2022.
5. Kuligowski, E.D., Gwynne, S.M.V., Xie, H. et al. (2023). *Simulating Evacuation of Humanitarian Settlements*. Fire Techno. [Available from: <https://doi.org/10.1007/s10694-023-01431-6>].
6. Douglas I. (1995). *Human settlements in Changes in Land use and land cover: A global Perspective*. Edited by William B. Meyer and B. L. Turner II, Cambridge University Press.
7. United Nations High Commissioner for Refugees (UNHCR) (1999). *Effective Planning Guidelines for UNHCR Teams*. (January 1999).
8. United Nations High Commissioner for Refugees (UNHCR) (2019) *The Master plan approach to settlement planning framework*. [Available from: https://emergency.unhcr.org/sites/default/files/UNHCR%20Master-Plan-Approach%20to%20Settlement%20Planning_2019.pdf].
9. Bibri S. E, Krogstie B. J. (2017). *Sustainable Cities and Society*, 2017 – Elsevier.

10. World Bank (2023). *World Development Report 2023 - Migrants, Refugees and Societies- A World Bank Group Flagship Report*. [Available at: <https://www.worldbank.org/en/publication/wdr2023>].
11. UNHCR, GRF (2023). *Climate resilient sustainable human settlements - Multistakeholder pledge guidance*.
12. World Bank (2018). *Urban Sustainability Framework, Global Platform for sustainable cities, p15, Word Bank*. [Available at: <https://doi.org/10.1596/29364>]
13. *UNHCR Policy on Emergency Preparedness and Response 2023*, 31 January 2023 | Publisher: UN High Commissioner for Refugees (UNHCR) | Document type: Operational Guidelines.
14. The United Nations (2023) *Global Water Security 2023 Assessment*. [Available at <https://reliefweb.int/report/world/global-water-security-2023-assessment>].
15. Bonyan Organization (2023). *Green Energy and Solar Panels for Refugee Camps*. [Available at <https://bonyan.ngo/displaced-and-refugees/solar-panels-in-refugee-camps/>].
16. Bardi U. (2023). *The Limits to Growth Revisited*. Springer Briefs in Energy – Energy Analysis.
17. Agier M. et Lecadet C. (2014) *Un monde de camps, Paris, France, la Découverte*.
18. UNHCR (2021). *Refugee camps explained*. [Available from: <https://www.unrefugees.org/news/refugee-camps-explained/>].
19. UNHCR (2019). *Evaluation of UNHCR's data use and information management approaches, Evaluation report November 2019*. Conducted by Ladek. S. and al.

20. Al-Saidi, M. and Elagib, N.A. (2017). *Towards understanding the integrative approach of the water, energy, and food nexus* (2017). *Science of The Total Environment - Volume 574*, 1 January 2017. [Available from: <https://pubmed.ncbi.nlm.nih.gov/27710905/>]
21. UNHCR (2020) *Kakuma Refugee Camp and Kalobeyei Integrated Settlement*. [Available at: <https://www.unhcr.org/ke/kakuma-refugee-camp>].
22. *UNHCR (2007) Handbook for Emergencies, Author: Emergency Preparedness and Response Section (EPRS) UN High Commissioner for Refugees (UNHCR)*
23. UNHCR, Kenyan's Department of Refugees Services (DRS), Jan 31, 2023. [Available at: <https://www.unhcr.org/ke/wp-content/uploads/sites/2/2023/02/Kenya-Refugee-Population-Statistics-Package-31-January-2023.pdf>].
24. UNHCR (2019). Monthly operational update. Kakuma Camp & Kalobeyei settlement. Kenya, UNHCR. [Available from: https://www.unhcr.org/ke/wp-content/uploads/sites/2/2022/04/UNHCR_Kenya_Kakuma_February_2022_Monthly_Operational_Updates.pdf]
25. UNHCR Microdata Library. [Available from: <https://microdata.unhcr.org/>].
26. UNHCR Global Strategy for Settlement and Shelter A UNHCR Strategy 2014-2018. [Available from: <https://emergency.unhcr.org/sites/default/files/UNHCR%20Global%20Strategy%20for%20Settlement%20and%20Shelter%202014-2018.pdf>]
27. UN-Habitat (2016) *United Nations Conference on Human Settlements*. Vancouver, Canada, 31 May to 11 June 1976.
28. Zivkovic. J. October 2019, *Human settlements, and climate change action* pp 1–11. Springer International Publishing.

29. Ramadan A. (April 2012). Spatializing the refugee camp. [Available at: <https://doi.org/10.1111/j.1475-5661.2012.00509.x>].
30. Oesch L. (2020). *An Improvised Dispositif: Invisible Urban Planning in the Refugee Camp*. Published by the International Journal of Urban and Regional Research.
31. Brankamp H. (2021) *Feeling the refugee camp - Affectual research, bodies, and suspicion*. [Available at: <https://doi.org/10.1111/area.12739>].
32. García-Díaz, C. and Olaya, M. (2017) *Social systems engineering: The design of complexity*. Publisher by Wiley series in computational and quantitative social science.
33. T. Yasmin, S. Dhesi, I. Kuznetsova, R. Cooper, S. Krause and I. Lynch - International Journal of Water Resources Development, November 2022.
34. Zhuang, Y. (2014). A System Dynamics Approach to Integrated Water and Energy Resources Management. Ph.D. Dissertation, University of South Florida
35. Nadir Ahmed Elagib, Mohammad Al-Saidi. (2020) - *Balancing the benefits from the water–energy–land–food nexus through agroforestry in the Sahel*. Science of the Total Environment. [Available from: <https://doi.org/10.1016/j.scitotenv.2020.140509>].
36. Ghodsvali M. et al. (2023). *An integrated decision support system for the urban food-water-energy nexus: methodology, modification, and model formulation*. *Information Systems in the Built Environment, EAISI Mobility, Real Estate and Urban Development*.
37. Mansour et al. (Sep 2022). *Multi-criteria approach for the selection of water, energy, food nexus assessment tools and a case study application*.
38. Kaddoura, S., & El Khatib, S. (2017). *Review of water-energy-food nexus tools to improve the nexus modelling approach for integrated policy making*. *Environmental Science and Policy*, 77, 114–121. (Elsevier Ltd.).

39. Chi Zhang et al (2018). *Water-energy-food nexus: Concepts, questions, and methodologies*. Journal of Cleaner Production. Volume 195, 10 September 2018.
40. Weitz N. et al (2017) *Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance*. - *Global Environmental Change*. Volume 45, July 2017, Pages 165-173.
41. N Vakilifard, M Anda, PA Bahri, G Ho (2018). *The role of water-energy nexus in optimizing water supply systems—review of techniques and approaches*. - *Renewable and Sustainable Energy*, 2018 - Elsevier.
42. Ringler, A. et al (2013). *The nexus across water, energy, land, and food (WELF): potential for improved resource use efficiency*. Elsevier, Current Opinion in Environment Sustainability.
43. Amadei, B. (2019). *A Systems Approach to Modeling the Water-Energy-Land-Food Nexus, Volume I: Defining and Analyzing the Landscape*. Momentum Press Engineering
44. Cheshmehzang. A. (2020). *Evaluating the Nexus between Housing and Energy Sectors: The Comparison of Urban, Peri-Urban and Rural Housing Areas in Zhuhai, China*.
45. Meehan. K. et al (2020). *Geographies of insecure water access and the housing–water nexus in US cities*. Edited by William A. V. Clark, University of California, Los Angeles, CA.
46. Dunga. H. S. and Grobler, W C J (2017). *The Nexus of Food and Housing insecurity in South Africa: the case of Bophelong and Sharpeville townships*. The International Journal of Social Sciences and Humanity Studies; Izmir.

47. Ostovar, A. (2020) *A Study on the Impact of Water on Housing Development on the Monterey Peninsula*. [Available at: <https://mbep.biz/wp-content/uploads/2020/04/Housing-and-Water-Blue-Paper.pdf>].
48. UNHCR (revision 2023) *UNHCR Camp site planning minimum standards*. [Available at: <https://emergency.unhcr.org>].
49. United Nations High Commissioner for Refugees (2013) UNHCR Policy on alternatives to camps. [Available from: <https://www.unhcr.org/sites/default/files/legacy-pdf/5422b8f09.pdf>].
50. UNHCR. *Kalobeyei Settlement*. [Available from: <https://www.unhcr.org/ke/kalobeyei-settlement>]
51. Joint Data Center on Forced Displacement. (September 2022). *The Impact of Forced Displacement on Housing and Urban Settlement in Host Communities – JDC Quarterly Digest | Sixth Issue*.
52. Jorgensen, R. *Defining Operational Concepts Using SysML: System Definition from the Human Perspective*. In *Proceedings of the INCOSE International Symposium*. Wiley Online Library, 2011; Vol. 21, pp. 3005–3138.
53. Mansour et al (2022). *Multi-criteria approach for the selection of water, energy, food nexus assessment tools and a case study application*. - *Journal of Environmental Management*. Volume 322, 15 November 2022.
54. Bibri S. & Krogstie J. (2017). *On the social shaping dimensions of smart sustainable cities: A study in science, technology, and society*. [Available from: <https://www.sciencedirect.com/science/article/abs/pii/S2210670716305881>]

55. Lopez D. (2015). *On the social shaping dimensions of smart sustainable cities. A study in science, technology, and society.*
56. The Hague Academy (2024). *The key elements for integrated urban planning'' by The Hague Academy for Local Governance.* [Available from : <https://thehagueacademy.com/news/the-building-blocks-for-successful-urban-development-projects/>].
57. Yang, C. (2020). *Historicizing the Smart Cities: Genealogy as a Method of Critique for Smart Urbanism.* Telemat. Inform. 2020.
58. Professor Newton P. Swinburne (2006). *Human settlements by University of Technology Peer reviewers.* Theme commentary prepared for the 2006 Australian State of the Environment Committee, Department of the Environment and Heritage, Canberra.
59. Barrionuevo, J.M.; Berrone, P.; Ricart, J.E. *Smart Cities, Sustainable Progress.* IESE Insight 2012, 14, 50–57.
60. Teli, M.; Bordin, S.; Menéndez Blanco, M.; Orabona, G.; De Angeli, A. *Public Design of Digital Commons in Urban Places: A Case Study.* Int. J. Hum. - Comput. Stud. 2015.
61. Chen, T. *Smart Grids.* (2010). *Smart Cities Need Better Networks* [Editor's Note]. Netw. IEEE 2010, 24, 2–3.
62. UNHCR (2020) *Kakuma Refugee Camp and Kalobeyei Integrated Settlement.* [Available at: <https://www.unhcr.org/ke/kakuma-refugee-camp>].
63. Gascó-Hernandez, M. (2018). *Building a Smart City: Lessons from Barcelona.* Commun. ACM 2018, 61, 50–57.
64. Cilliers, L. Flowerday, S. (2017). *Factors That Influence the Usability of a Participatory IVR Crowdsourcing System in a Smart City.* South Afr. Comput. J. 2017, 29, 16–30.

65. Marsal-Llacuna, M.-L.; Colomer-Llinàs, J.; Meléndez-Frigola, J. (2015). *Lessons in Urban Monitoring Taken from Sustainable and Livable Cities to Better Address the Smart Cities Initiative*. Technol. Forecast. Soc. Change 2015, 90, 611–622.
66. Breetzke, T.; Flowerday, S.V. (2016). *The Usability of IVRs for Smart City Crowdsourcing in Developing Cities*. Electron. J. Inf. Syst. Dev. Ctries. 2016, 73, 1–14, doi:10.1002/j.
67. Eger, J.M. (2009). *Smart Growth, Smart Cities, and the Crisis at the Pump a Worldwide Phenomenon*. WAYS- J. E-Gov. Policy Regul. 2009, 32, 47–53.
68. Zhuhadar, L. Thrasher, E Marklin, S. de Pablos, P.O. (2017). *The next Wave of Innovation - Review of Smart Cities Intelligent Operation Systems*. Comput. Hum. Behav.
69. Guan, L. (2012). *Smart Steps to a Better City*. Gov. News 2012, 32, 24.
70. Yeh, H. (2017). *The Effects of Successful ICT-Based Smart City Services: From Citizens' Perspectives*. Gov. Inf. Q. 2017, 34, 556–565.
71. Giffinger, R.; Fertner, and Al (2017). *Smart Cities: Ranking of European Medium-Sized Cities*. Vienna, Austria: Centre of Regional Science (Srf). Vienna University of Technology.
72. Schuurman, D. Baccarne, B. De Marez, L. ; Mechant, P. (2012). *Smart Ideas for Smart Cities: Investigating Crowdsourcing for Generating and Selecting Ideas for ICT Innovation in a City Context*. J. Theor. Appl. Electron. Commer. Res. 2012, 7, 49–62.
73. Komninos, N. (2009). *Intelligent Cities: Towards Interactive and Global Innovation Environments*. Int. J. Innov. Reg. Dev. 2009, 1, 337–355.
74. Li, D.; Yao, Y.; Shao, Z.; Wang, L. (2014). *From Digital Earth to Smart Earth*. Chin. Sci. Bull. 2014, 59, 722–733.

75. Kourtiti, K. Nijkamp, P. Arribas, D. (2012). *Smart Cities in Perspective—a Comparative European Study by Means of Self-Organizing Maps*. *Innov. Eur. J. Soc. Sci. Res.*
76. Calderoni, L. Maio, D. Rovis, S. (2014). *Deploying a Network of Smart Cameras for Traffic Monitoring on a “City Kernel.”* *Expert Syst. Appl.* 2014.
77. Ortiz-Fournier, L.V. et Al. (2010). *Integrating Educational Institutions to Produce Intellectual Capital for Sustainability in Caguas, Puerto Rico*. *Knowl. Manag. Res. Pract.* 2010, 8, 203–215.
78. Khatoun, R.; Zeadally, (2016). S. *Smart Cities: Concepts, Architectures, Research Opportunities*. *Commun. ACM* 2016, 59, 46–57.
79. Zygiaris, S. (2013). *Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems*. *J. Knowl. Econ.* 2013, 4, 217–231.
80. United Nations Human Settlements Programme (UN-Habitat) and United Nations High Commissioner for Refugees (UNHCR) 2020. *Guidance for Responding to Displacement in Urban Areas*.
81. UN Centre for Housing, Building and Planning, 1974. *Human Settlements: The Environmental Challenge*. London: Macmillan.
82. United Nations High Commissioner for Refugees (UNHCR) (2015) *What is a refugee camp?* [[Available at: https://www.unrefugees.org](https://www.unrefugees.org)].
83. UNHCR (2017) *Resilience and self-reliance from a protection and solutions perspective*. - *Executive Committee of the UNHCR’s Programme (EC/68/SC/CRP.4)*, 1 March 2017.
84. World Bank (2018) *Urban Sustainability Framework, Global Platform for sustainable cities*. February 2018. [[Available at: https://doi.org/10.1596/29364](https://doi.org/10.1596/29364)].

85. *Sustainable development and human settlements, March 2003* |ECLAC Series»
Environment and Development.- [Available from:
<https://www.cepal.org/en/topics/sustainable-development-and-human-settlements>].
86. IRC (2019) *Missing Persons: Refugees Left Out and Left Behind in the SDG*. [Available from: [https://migrationdata portal.org/resource/missing-persons-refugees-left-out-and-left-behind-sdgs](https://migrationdata.portal.org/resource/missing-persons-refugees-left-out-and-left-behind-sdgs)].
87. UNHCR. *Kalobeyei integrated socio-economic development plan in Turkana West*. December 2018. [Available from: <https://www.unhcr.org/ke/wp-content/uploads/sites/2/2018/12/KISED.PDF>].
88. Muvuna, J.; Boutaleb, T.; Mickovski, S.B.; Baker, K.J. (2016). *Systems Engineering Approach to Design and Modelling of Smart Cities*. In *Proceedings of the 2016 International Conference for Students on Applied Engineering (ICSAE)*. pp. 437–440.
89. Sturiale L. and Scuderi A. (2019). *The Role of Green Infrastructures in Urban Planning for Climate Change Adaptation*. Submission received: 31 July 2019 / Revised: 16 September 2019 / Accepted: 28 September 2019 / Published: 4 October 2019.
90. Mongeau-s, S. (2012). *An Integrated Platform for Smart City Design: Structured Market-Based Incentive Architecture Design for Sustainable ‘System of Systems’ Supply Chain Orchestration*.
91. Kossiakoff. A. et al. *Systems Engineering Principles and Practice*. – Second Edition, 2011 - Copyright © 2011 John Wiley & Sons, Inc.
92. INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2.

93. Beery, P.T. A (2016). *Model-Based Systems Engineering Methodology for Employing Architecture in System Analysis: Developing Simulation Models Using Systems Modeling Language Products to Link Architecture and Analysis*. Naval Postgraduate School Monterey Ca Monterey United States, 2016.
94. John M. Borcky J. & Bradley T. *Effective Model-Based Systems Engineering*, - ISBN 978-3-319-95668-8 ISBN 978-3-319-95669-5 [eBook available from: <https://doi.org/10.1007/978-3-319-95669-5>.]
95. Boehm, B.W. (1988). *A Spiral Model of Software Development and Enhancement*. Computer 1988, 21, 61–72.
96. A Practical Guide to SysML, Third Edition, fully updated for SysML version 1.4.
97. Madni, A.M.; Sievers, M. (2018). *Model-Based Systems Engineering: Motivation, Current Status, and Research Opportunities*. Syst. Eng. 2018, 21, 172–190, doi:10.1002/sys.21438.
98. Jorgensen, R. *Defining Operational Concepts Using SysML: System Definition from the Human Perspective*. In *Proceedings of the INCOSE International Symposium*. Wiley Online Library, 2011; Vol. 21, pp. 3005–3138.
99. JA Estefan (2007). *Survey of model-based systems engineering (MBSE) methodologies - INCOSE MBSE Focus Group*. Available from: [https://edisciplinas.usp.br/pluginfile.php/5348231/mod_resource/content/1/MBSE Metho dology_Survey_RevB.pdf](https://edisciplinas.usp.br/pluginfile.php/5348231/mod_resource/content/1/MBSE_Metho dology_Survey_RevB.pdf).
100. Karban, R.; Weilkiens, T.; Hauber, R.; Zamparelli, M.; Diekmann, R.; Hein, A. (2011). *Cookbook for MBSE with SysML. MBSE Initiat. -SE2 Chall. Team 2011*.

101. Hossain, N.U.I.; Jaradat, R.M.; Hamilton, M.A.; Keating, C.B.; Goerger, S.R. A Historical *Perspective on Development of Systems Engineering Discipline: A Review and Analysis*. J. Syst. Sci. Syst. Eng. 2020, 29, 1–35, doi:10.1007/s11518-019-5440-x.
102. Paredis, C. (2011). *Model-Based Systems Engineering: A Roadmap for Academic Research*. Front. Model-Based Systems Engineering. Atlanta GA 2011.
103. Oscar W. Nabiswa (2021). *Evaluation of the efficiency of water supply and distribution systems in Kakuma refugee camp*. University of Nairobi, School of Engineering.
104. *SysML-Based Design Chain Information Modeling for Variety Management in Production Reconfiguration*, November 2011 (Journal of Intelligent Manufacturing 24(3)).
105. A.J.G. Silvius, and al. (2017). *An investigation using Q-methodology,*” *International Journal of Project Management*, vol. 35, no. 6, pp. 1133-1150, 2017.
106. The SAGE Handbook of Interview Research: *The Complexity of the Craft*, 2001. [Available from: <https://methods.sagepub.com/book/handbook-of-interview-research-2e>].
107. Shemmings. D, T. Ellingsen. Published: 2014, Sage Research Methods. Available at: <https://doi.org/10.4135/9781452218403>. The SAGE Handbook of Interview Research: The Complexity of the Craft.
108. Blond. K (2023). *An Enterprise System Engineering Analysis of KC-46A Maintenance Program Decision-Making*.
109. *Guidance for Preparing Standard Operating Procedures (SOPs)* EPA QA/G-6, United States Environmental Protection Agency, April 2007.
110. Hackett. Steven (2011). *Environmental and Natural Resources Economics: Theory, Policy, and the Sustainable Society*, January 2011.

111. LæssØe, Jeppe (2010). *Education for sustainable development, participation, and socio-cultural change* - Pages 39-57 | Received 28 May 2008, Accepted 20 Sep 2009, Published online: 17 Feb 2010.
112. Lavergne, R., & Saxby, J. (2001). *Capacity Development: Vision and Implication (pp. 1-11)*. *Capacity Development Occasional Series, Vol. 6088*, Canadian International Development Agency.
113. Måns Felleson. (2023). *A Sustainable Solution or Just a Different Form of Humanitarian Assistance? Examining the Kalobeyi Integrated Socio-Economic Development Plan (KISED P)*, *Refugee Survey Quarterly*, Volume 42, Issue 2, June 2023. [Available from: <https://doi.org/10.1093/rsq/hdad001>].
114. Betts A., Omata N, Sterck O. (2020) The Kalobeyi Settlement: A Self-reliance Model for Refugees? *Journal of Refugee Studies*, Volume 33, Issue 1, March 2020, Pages 189–223. [Available from: <https://doi.org/10.1093/jrs/fez063>].
115. CRGEC (Committee for Research on Global Environmental Change) 1991. *Report on the working group on land use change*. *Social Science Research Council*. Washington DC.
116. United Nations High Commissioner for Refugees (UNHCR), NRC (2018). *A study on prices, products, and priorities of clean, safe, and affordable energy in Kakuma refugee camp*. *Moving Energy Initiative (MEI) & Energy 4 Impact*. [Available at: <https://energy4impact.org/news/moving-energy-initiative-brings-clean-energy-and-improves-livelihoods-kakuma-refugees>].
117. Bouabid A, Garrick E L. (2016) *Capacity factor analysis for evaluating water and sanitation infrastructure choices for developing communities* - PMID: 26203872 - DOI: [10.1016/j.jenvman.2015.07.012](https://doi.org/10.1016/j.jenvman.2015.07.012)

118. Godet, M. (2006). *Creating Futures: Scenario Planning as a Strategic Management Tool. Economica.*
119. Fauzi A. & Rahma H. (2019), *Development of a Composite Measure of Regional Sustainable Development in Indonesia.* [Available from: <https://doi.org/10.3390/su11205861>]
120. Fauzi H. & Svensson Goran S. (2010) *Triple Bottom Line as Sustainable Corporate Performance: A Proposition for the Future* – [Available from <http://dx.doi.org/10.3390/su2051345>]
121. Ratnasari E. A. et al (2023). *Small-scale Vannamei shrimp farm business sustainability analysis with MICMAC: A study on Kebumen Coastal Area, Indonesia.*
122. Amadei B. (2020). *Challenges Article: A Systems Approach to Building Community Capacity and Resilience.*
123. Benjumea-Arias M. et al. (2016) *Structural Analysis of Strategic Variables through MICMAC Use: Case Study.* [Available from: https://www.researchgate.net/profile/Alejandro-Valencia-Arias/publication/305272221_Structural_Analysis_of_Strategic_Variables_through_MICMAC_Use_Case_Study/links/578d610708ae59aa66815b96/Structural-Analysis-of-Strategic-Variables-through-MICMAC-Use-Case-Study.pdf]
124. Gordon T. and Olaf Helmer (1966) *Social Technology.* [Available from: <https://apps.dtic.mil/sti/citations/tr/AD0460520>]
125. Adjahossou A. Kalobeyei settlement and Kakuma camp surveys on access to water, energy and shelter result analysis – October 2023. [Available from: [Kalobeyei Responses on Shelter, Water and Energy.pdf](#)].

126. UNHCR, *KISED P Progress Report July 2019 - June 2021*. [Available at: <https://www.unhcr.org/ke/wp-content/uploads/sites/2/2022/03/KISED P-progress-report-July-2019-June-2021.pdf>].
127. UNHCR (2022). *KKCF – Kakuma Kalobeyei Challenge Fund, Result Reporting 2022*.
128. UN-HABITAT, *Kakuma-Kalobeyei future vision: Enhancing Self Reliance for Refugees and Hosting Communities in Turkana West, Nairobi*, UN-HABITAT, 2022.
129. Måns Fellesson. (2023). *A Sustainable Solution or Just a Different Form of Humanitarian Assistance? Examining the Kalobeyei Integrated Socio-Economic Development Plan (KISED P)*, *Refugee Survey Quarterly*, Volume 42, Issue 2, June 2023. [Available from: <https://doi.org/10.1093/rsq/hdad001>].
130. UNHCR (2019) *Including Forced Displacement in the SDGs: A New Refugee Indicator*: [Available from: <https://www.unhcr.org/blogs/including-forced-displacement-in-the-SDGs-a-new-refugee-indicator/>].
131. United Nations (2017) *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*, March 2017. [Available from: <https://unstats.un.org>].
132. World Bank (2018) *Urban Sustainability Framework, Global Platform for sustainable cities*. February 2018. [Available at: <https://doi.org/10.1596/29364>].
133. UNHCR (2017) *Resilience and self-reliance from a protection and solutions perspective*. - *Executive Committee of the UNHCR’s Programme (EC/68/SC/CRP.4)*, 1 March 2017.
134. Adjahossou A. *Framework for Applying Sustainability Principles in Humanitarian Shelter Cluster Operations Through Systems Engineering Approach*. UNHCR Annual Global Shelter Cluster Workshop.

135. Adjahossou A. (2024). *Model-Based Systems Engineering Approach to Design a Human Settlement to Better Serve Displaced People*. *Journal Scientific Research*, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132350>].
136. Adjahossou A. (2024). *A Systems Approach to Assessing Sustainability Capacity in Kalobeyi Refugee Settlement in Kenya*. *Journal Scientific Research*, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132425>].
137. Adjahossou A. (2024). *A Triple Nexus Water-Energy-Housing (WEH) Framework Modelling Towards Improved Decision-Making in Humanitarian Operations*. *Journal Scientific Research*, 2024. [Available from: <https://www.scirp.org/journal/paperinformation?paperid=132447>]

APPENDIX A – SysML Block Definition Diagrams and Activity Diagrams

SysML Activity Diagrams of Figures 46 (idem 33), 47, 48, 49, and 50 illustrating the system behavior (Section 5.3)

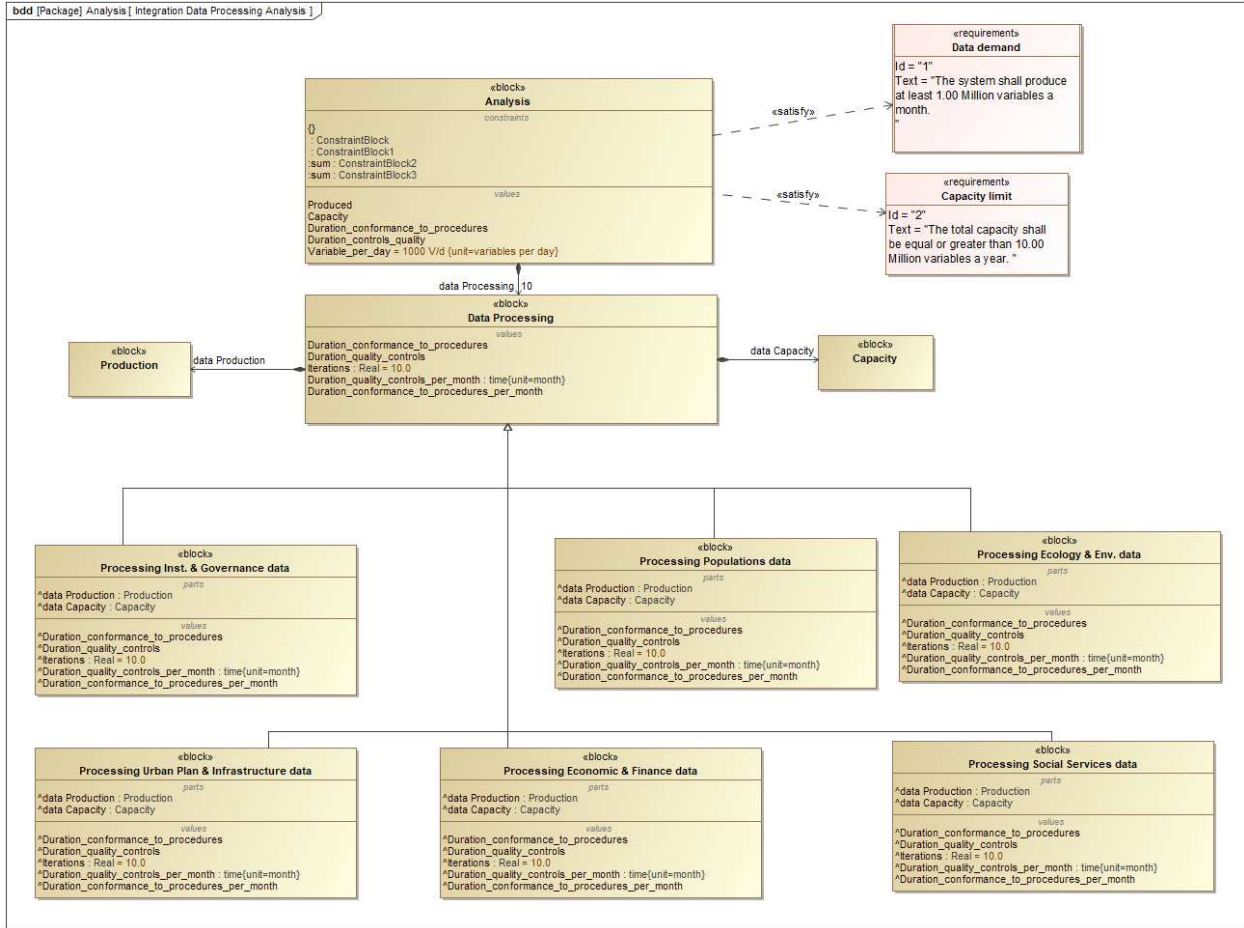


Figure 46: (idem 33): SysML Block Definition Diagram showing the System Requirements

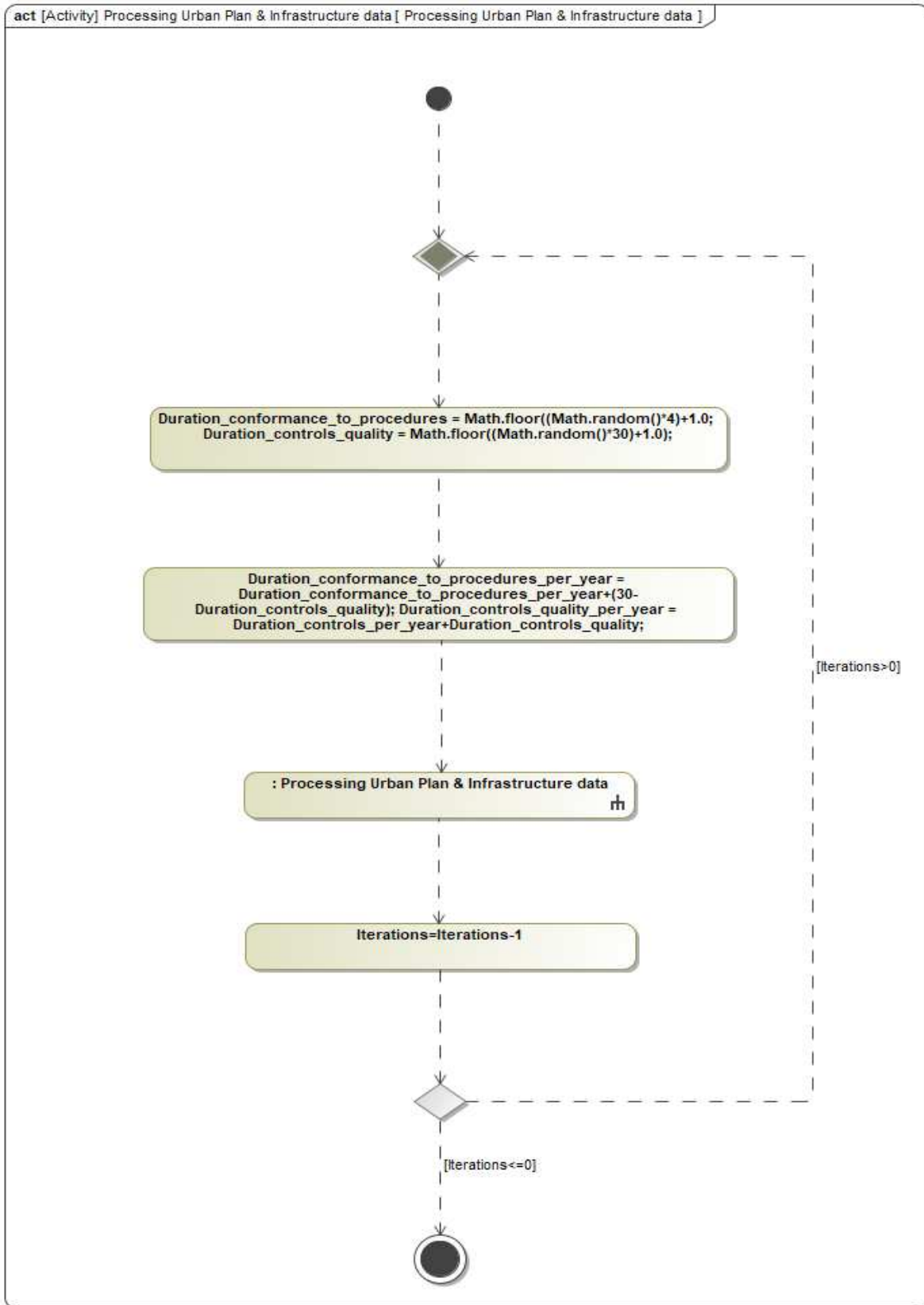


Figure 47: Activity Diagram showing Data Processing from the Urban Planning Sub-System

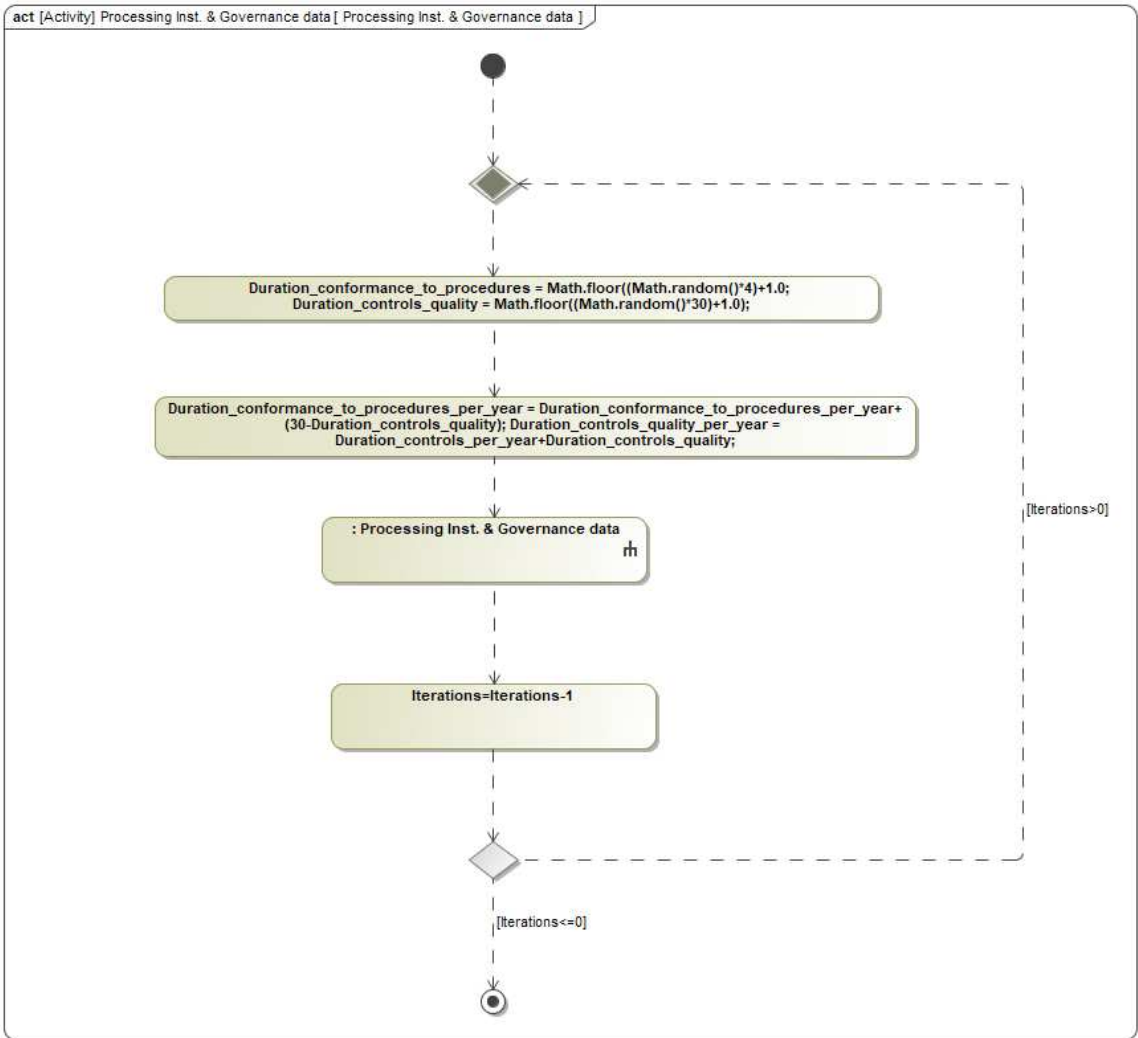


Figure 48: Activity Diagram showing Data Processing from the Institutional Sub-system

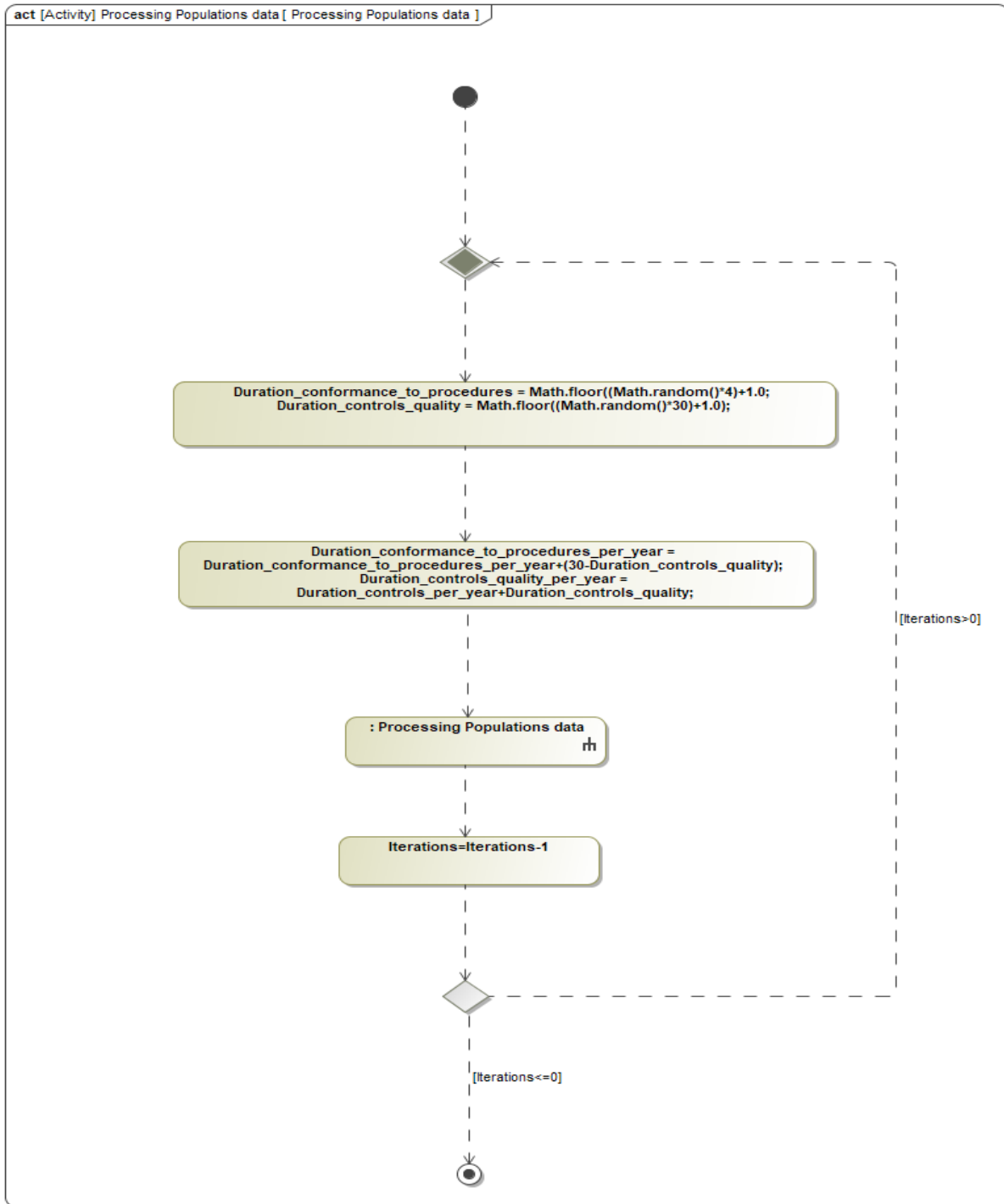


Figure 49: SysML Activity Diagram showing Data Processing from the Population Subsystem

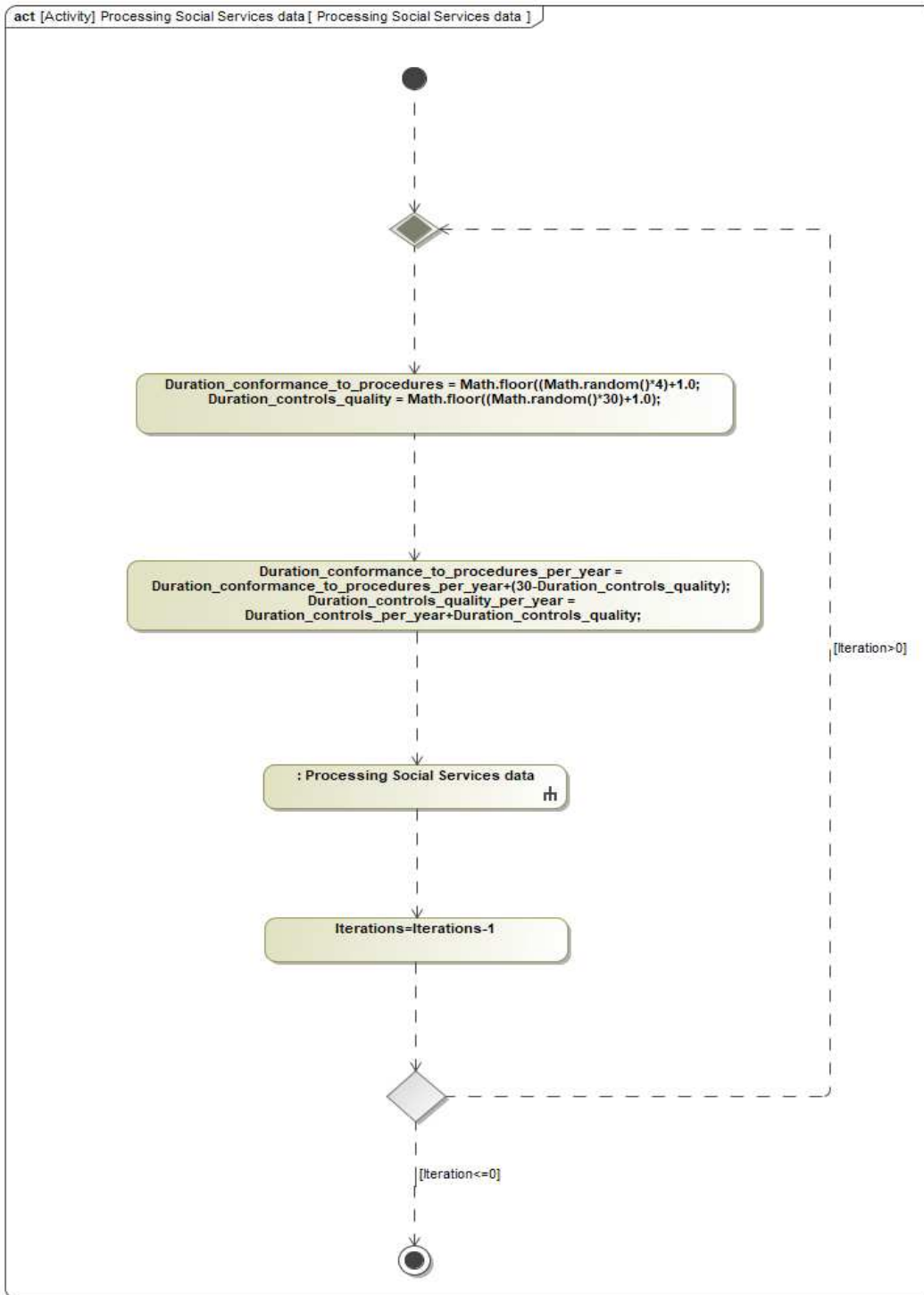


Figure 50: Activity Diagram showing Data Processing from the Social Services Subsystem

APPENDIX B – SysML Parametric Diagrams

SysML Parametric Diagrams of Figure 519 and Figure 52 illustrating the requirement constraints and the two scenarios (Section 5.3)

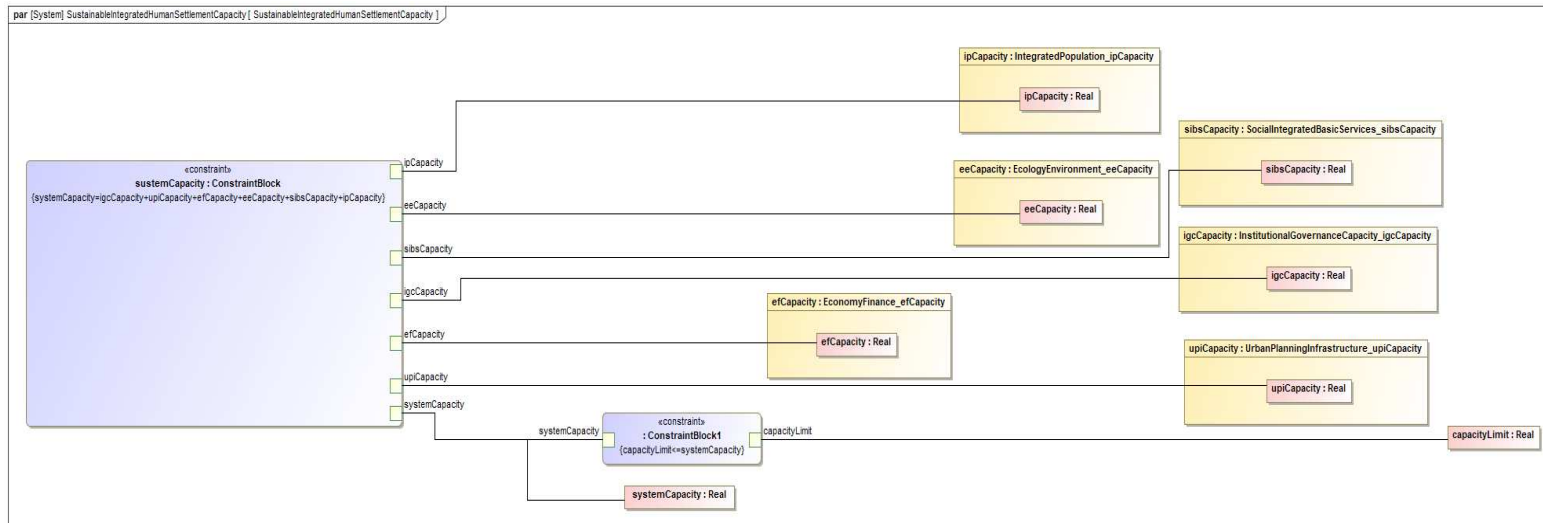


Figure 51: SysML Parametric Diagram showing the System Requirement Constraints

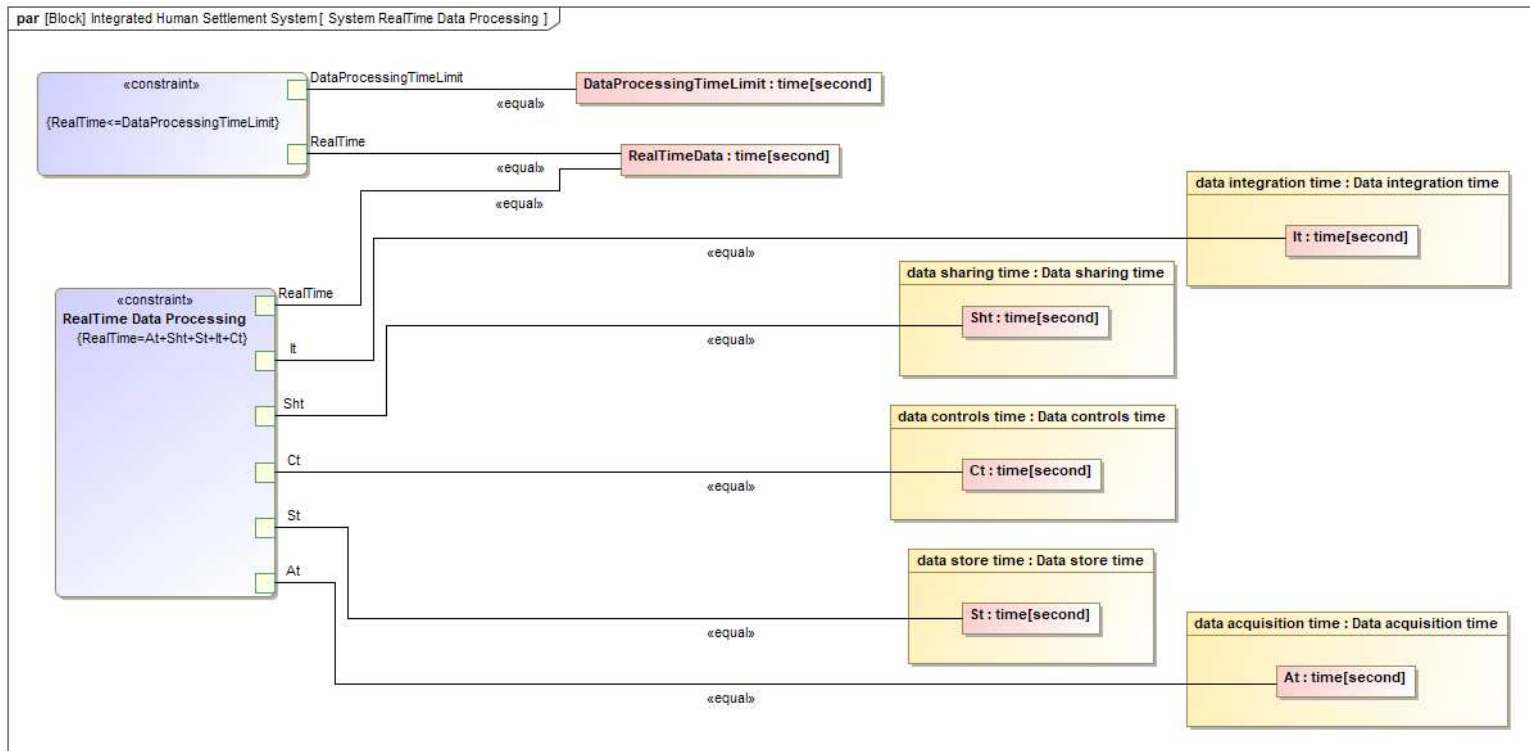


Figure 52: SysML Real Time Parametric Diagram showing System RT Constraints

APPENDIX C – SysML Parametric Diagrams and Block Definition Diagram

SysML Diagrams of Figures 53, 54, and 55 illustrating the two scenarios' results (Section 5.3)

```
par [System] SustainableIntegratedHumanSettlementCapacity [ SustainableIntegratedHumanSettlementCapacity ]
```

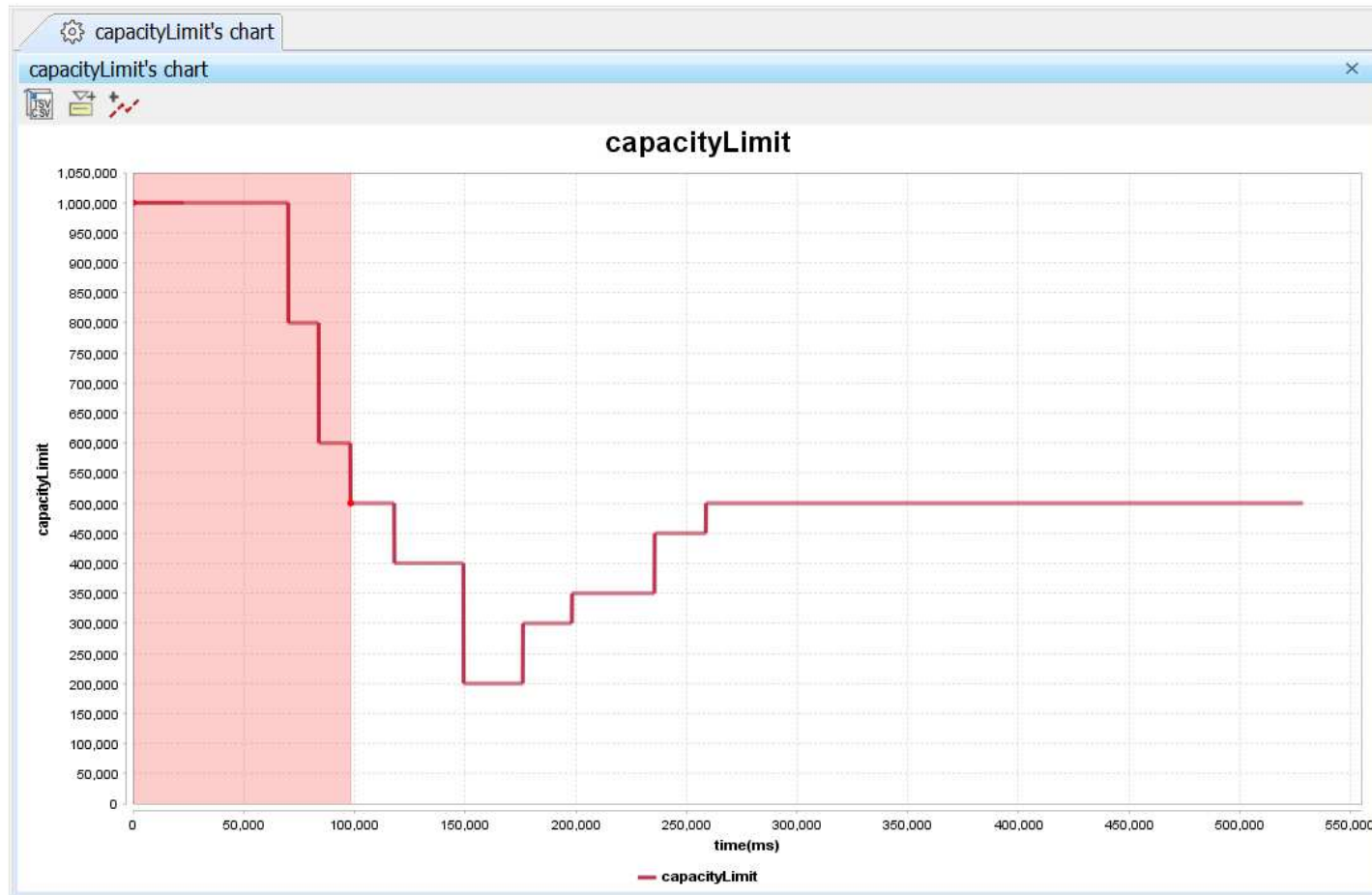


Figure 53: SysML Time Serie Chart showing the System Capacity Analysis Result

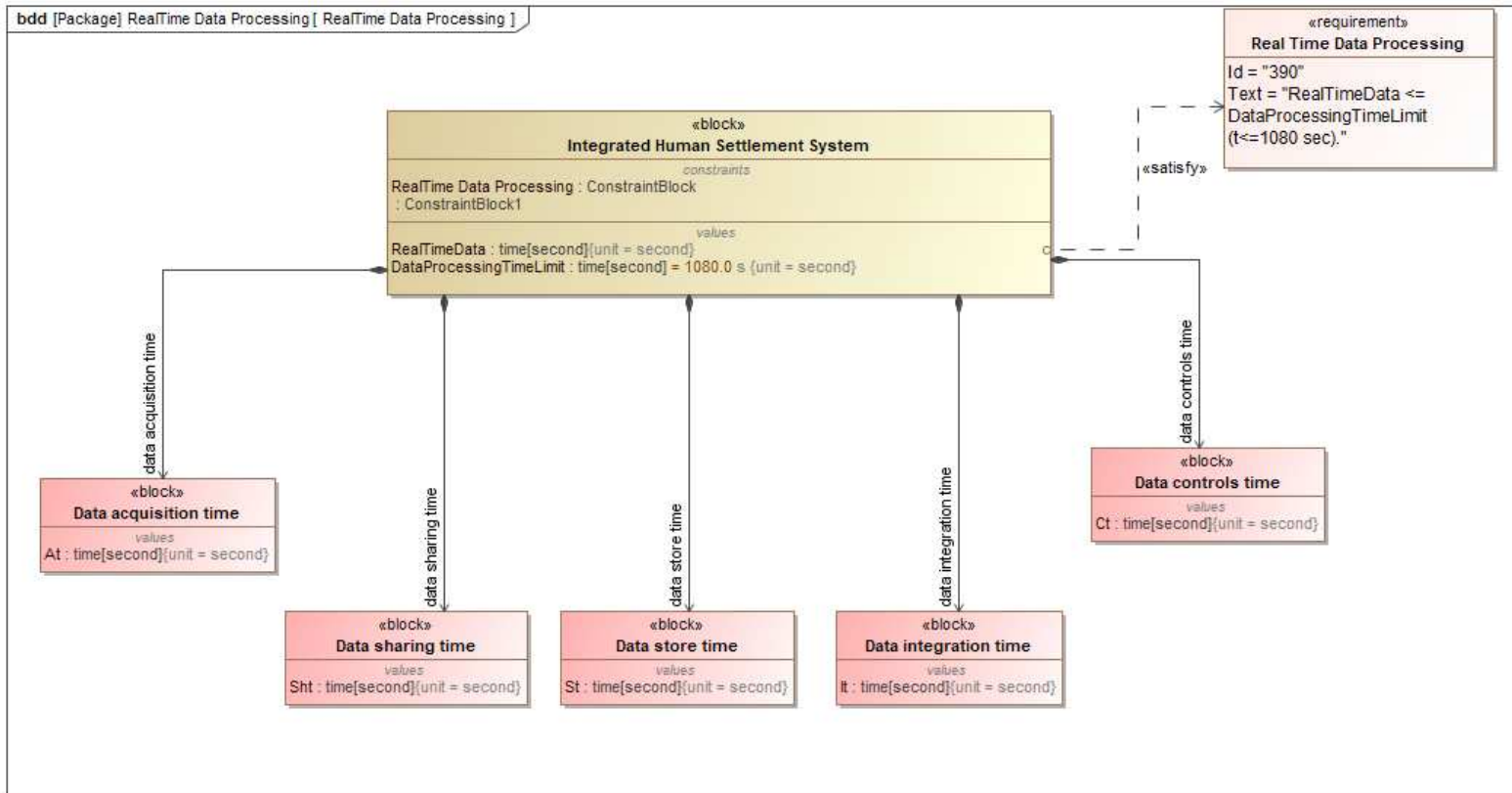


Figure 54: SysML Block Definition Diagram showing System Capacity in Real-Time (RT) Data Processing

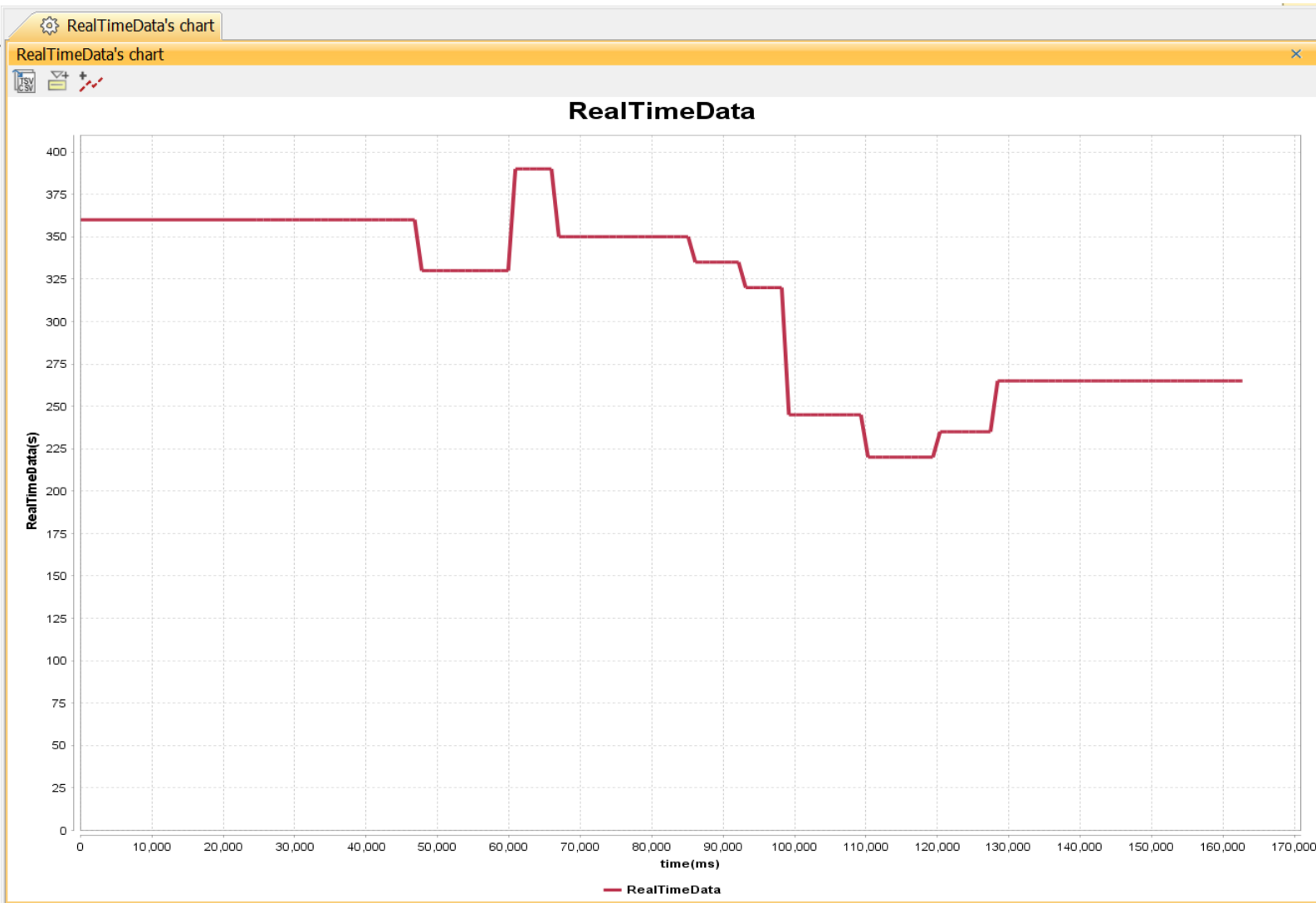


Figure 55: SysML Time Serie Chart showing RT Data Processing

APPENDIX D – SysML Block Definition Diagram showing Triple Nexus Optimization

SysML Diagrams showing optimization operations and results on Figures 56 (idem 32), 57, 58, 59, 60, 61, and 62. (Section 5.5).

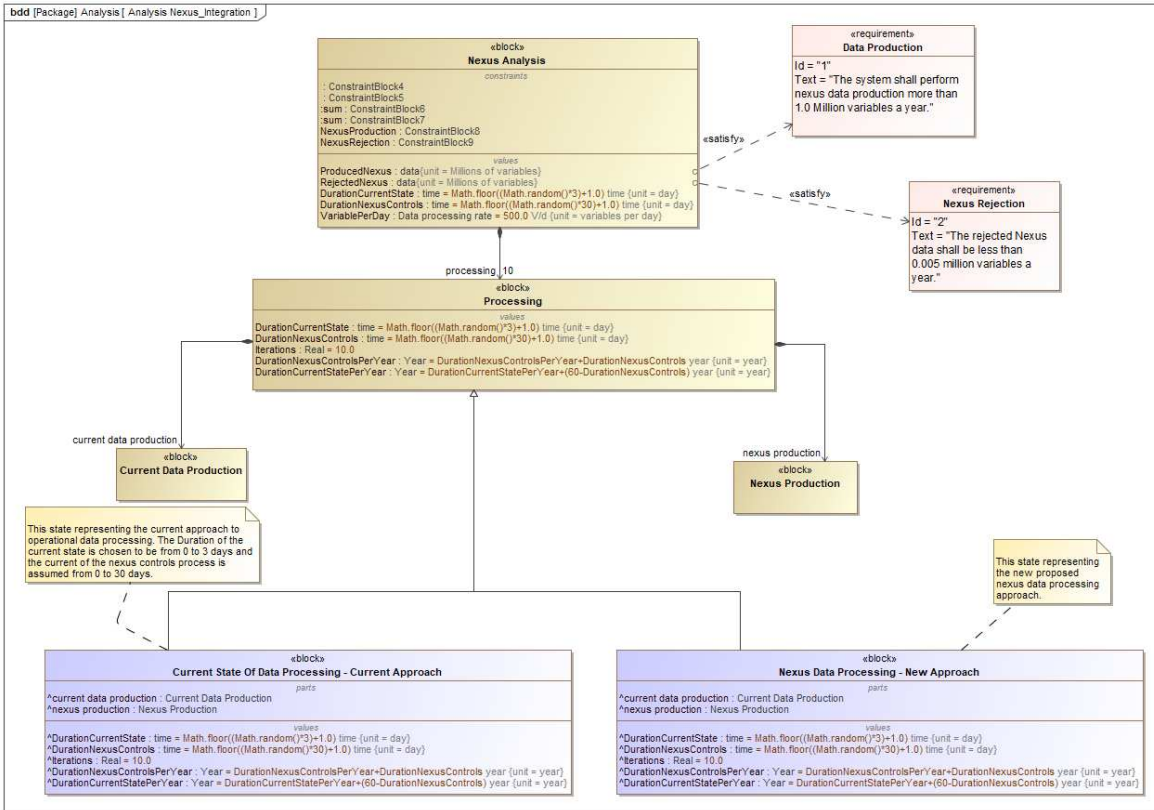


Figure 56: SysML Block Definition Diagram showing the Triple Nexus Data Processing

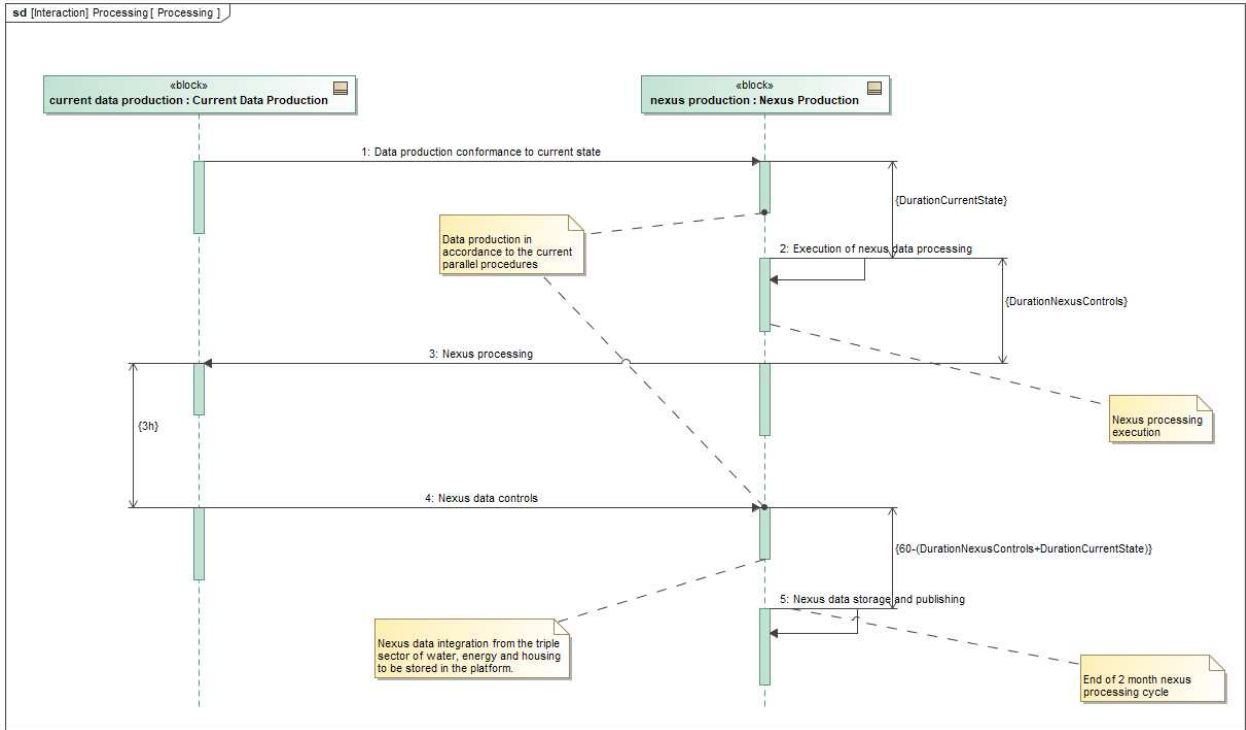


Figure 57: SysML Sequence Diagram showing Data Integration Process

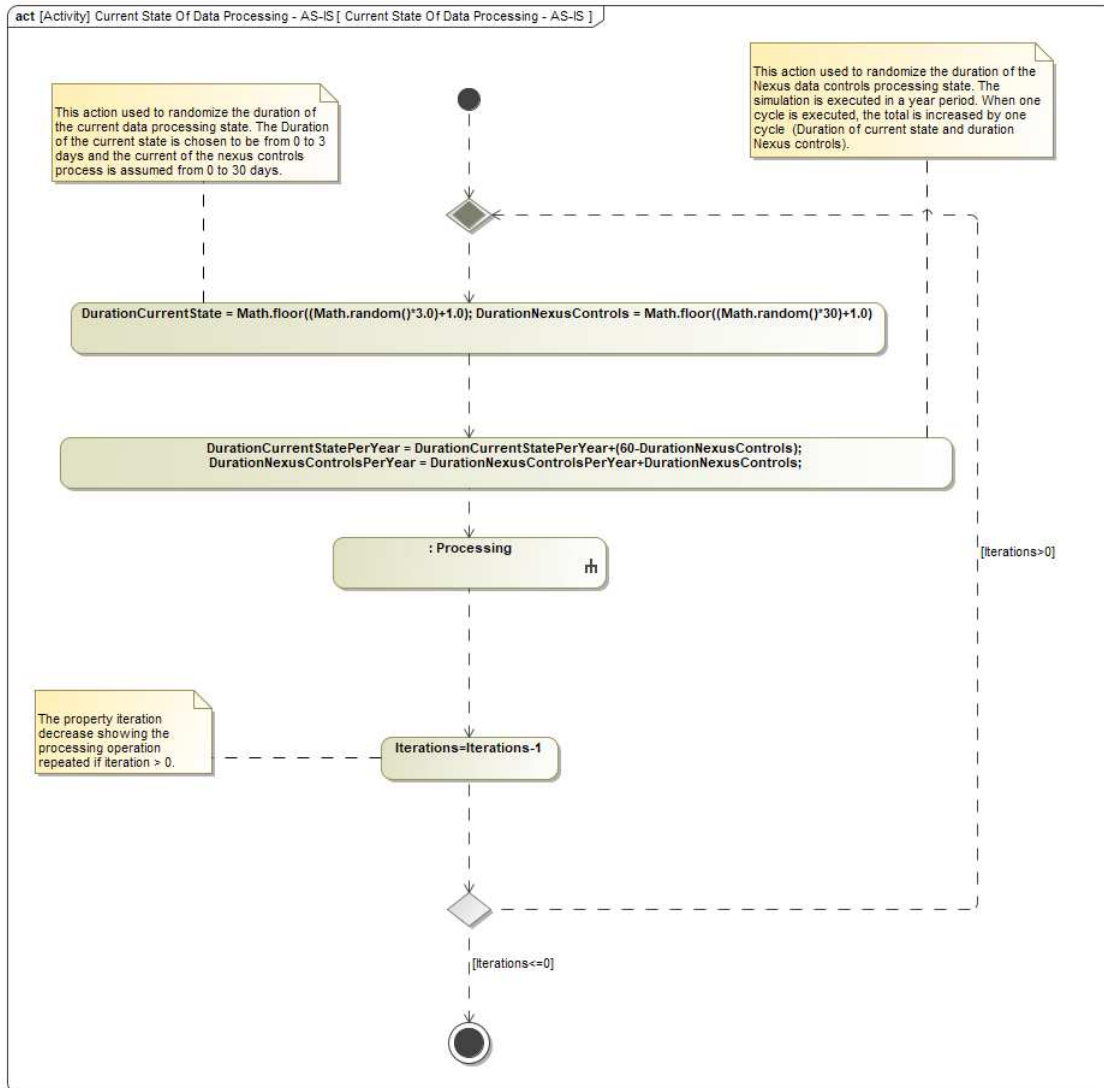


Figure 58: SysML Activity Diagram showing Properties Iteration based on the Proposed Nexus Data Processing

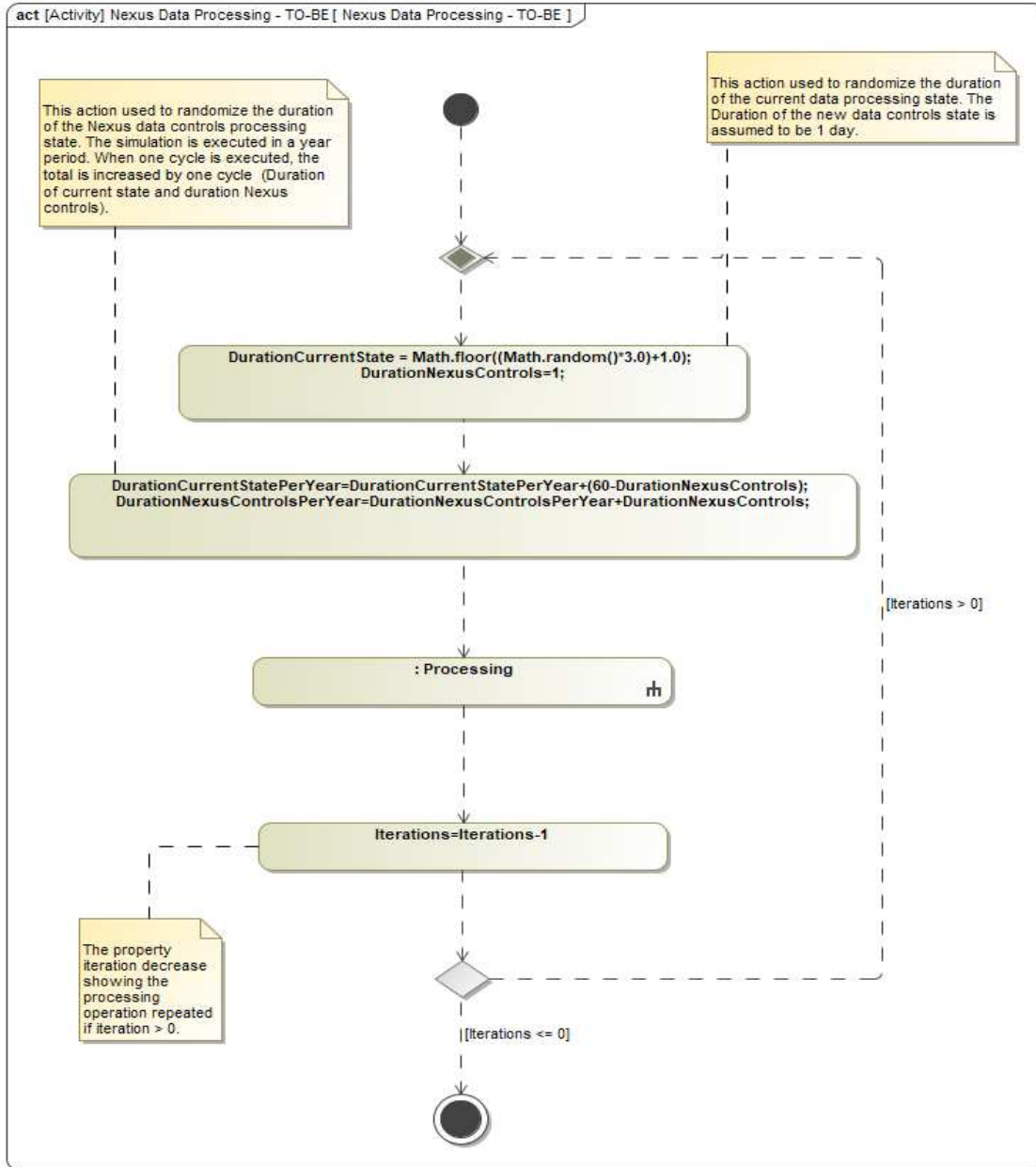


Figure 59: SysML Activity Diagram showing Properties Iteration based on the Current Data Processing

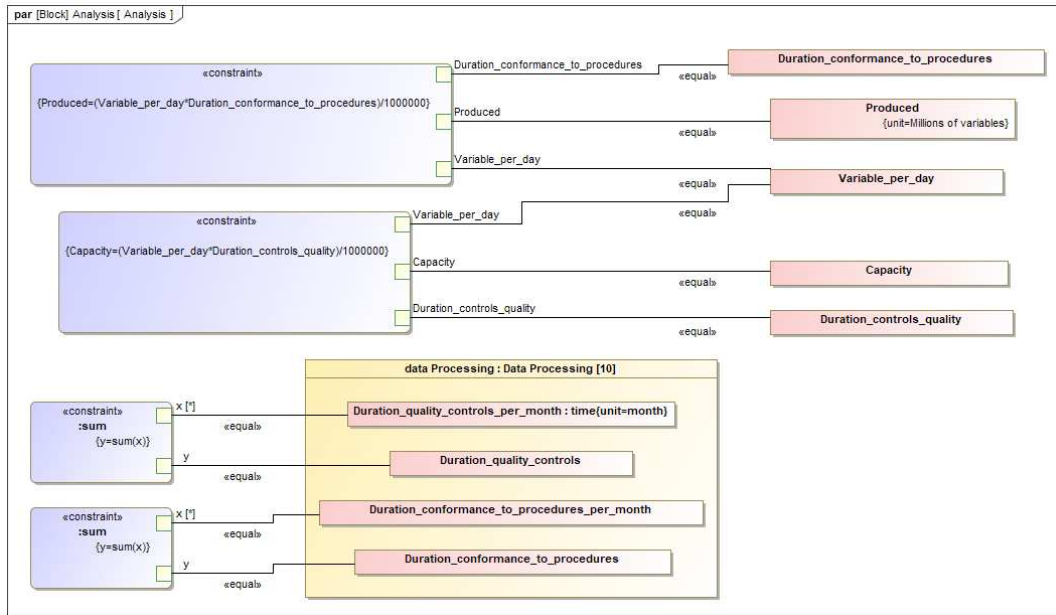


Figure 60: SysML Parametric Diagram of Triple Nexus Capacity Analysis

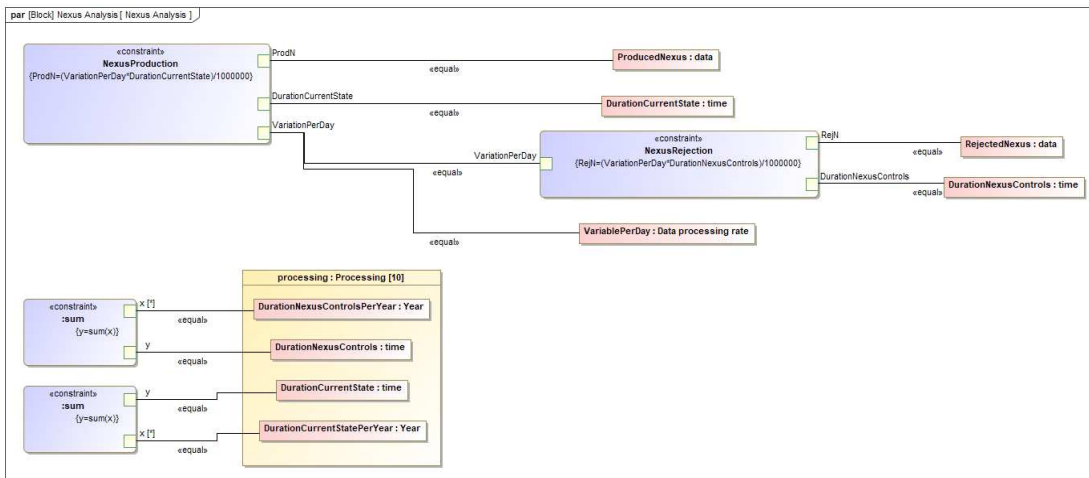


Figure 61: Parametric Diagram of Triple Nexus Optimization Process

#	Name	Production/News : data	Requests/News : data	Duration/Current/State : time	Duration/News/Control : time	Variable/Per/Day : Data processing rate
1	nexus_Analytic	3000 data	0.0095 data	2 time	19 time	500 data
2	nexus_Analytic1	2000 data	0.012 data	4 time	24 time	500 data
3	nexus_Analytic2	2000 data	0.013 data	4 time	30 time	500 data
4	nexus_Analytic3	2500 data	0.0075 data	5 time	7 time	500 data
5	nexus_Analytic4	1000 data	0.015 data	2 time	20 time	500 data
6	nexus_Analytic5	2500 data	0.0055 data	5 time	11 time	500 data
7	nexus_Analytic6	2200 data	0.0099 data	5 time	17 time	500 data
8	nexus_Analytic7	1500 data	0.0065 data	2 time	5 time	500 data
9	nexus_Analytic8	1300 data	0.0013 data	3 time	3 time	500 data
10	nexus_Analytic9	1000 data	0.0015 data	3 time	3 time	500 data

Figure 62: Nexus Optimization Simulation Configuration Results

APPENDIX E - Triple Nexus Framework Modeling SysML Diagrams

Figures 63 (idem 40) and 64 (idem 41) showing SysML Activity Diagram for Nexus Framework Behavior Model and the Decision Support Process (Adapted from [104]).

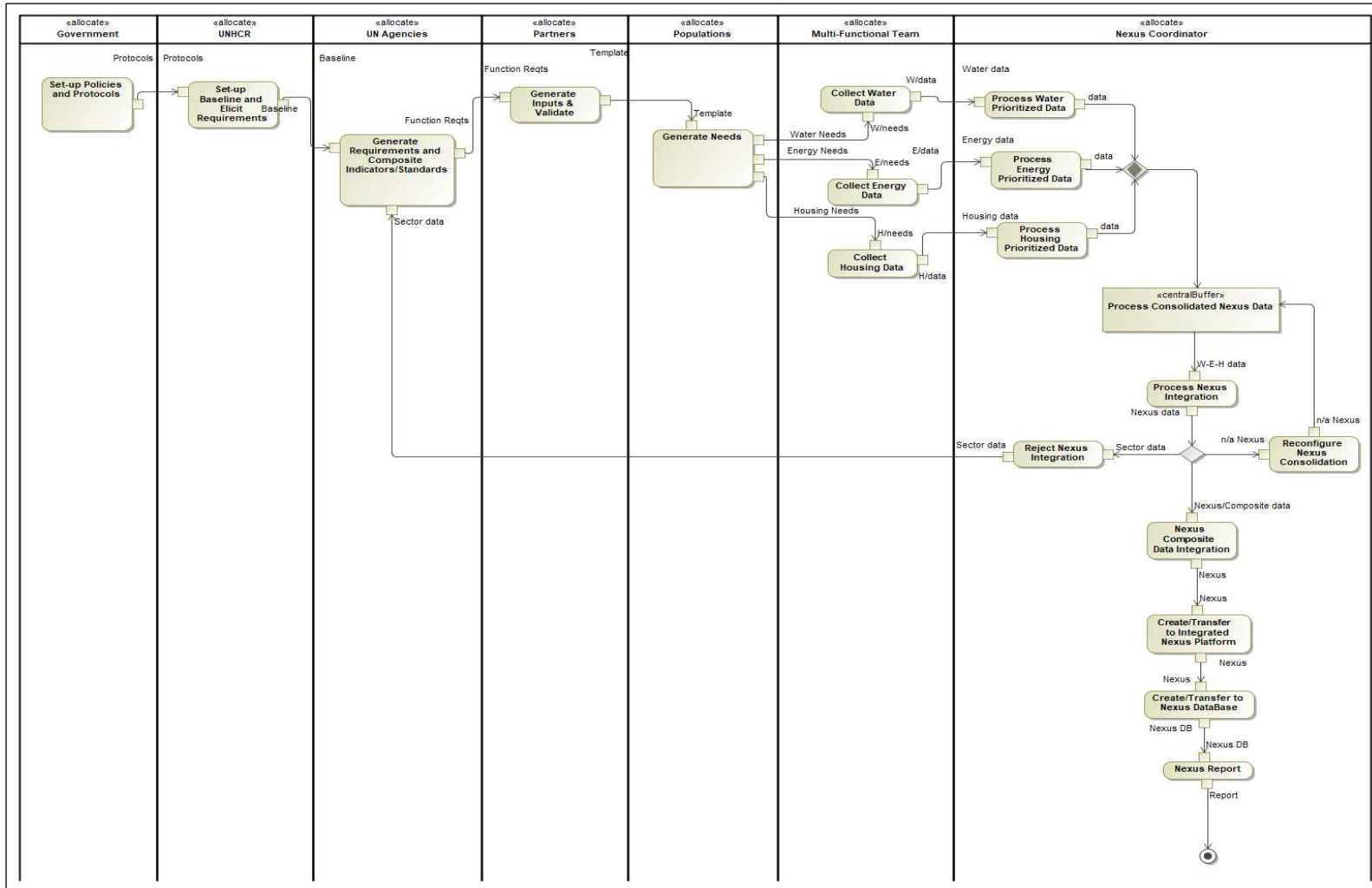


Figure 63: (idem 40) SysML Activity Diagram for Nexus Framework Behavior Model (Adapted from [104])

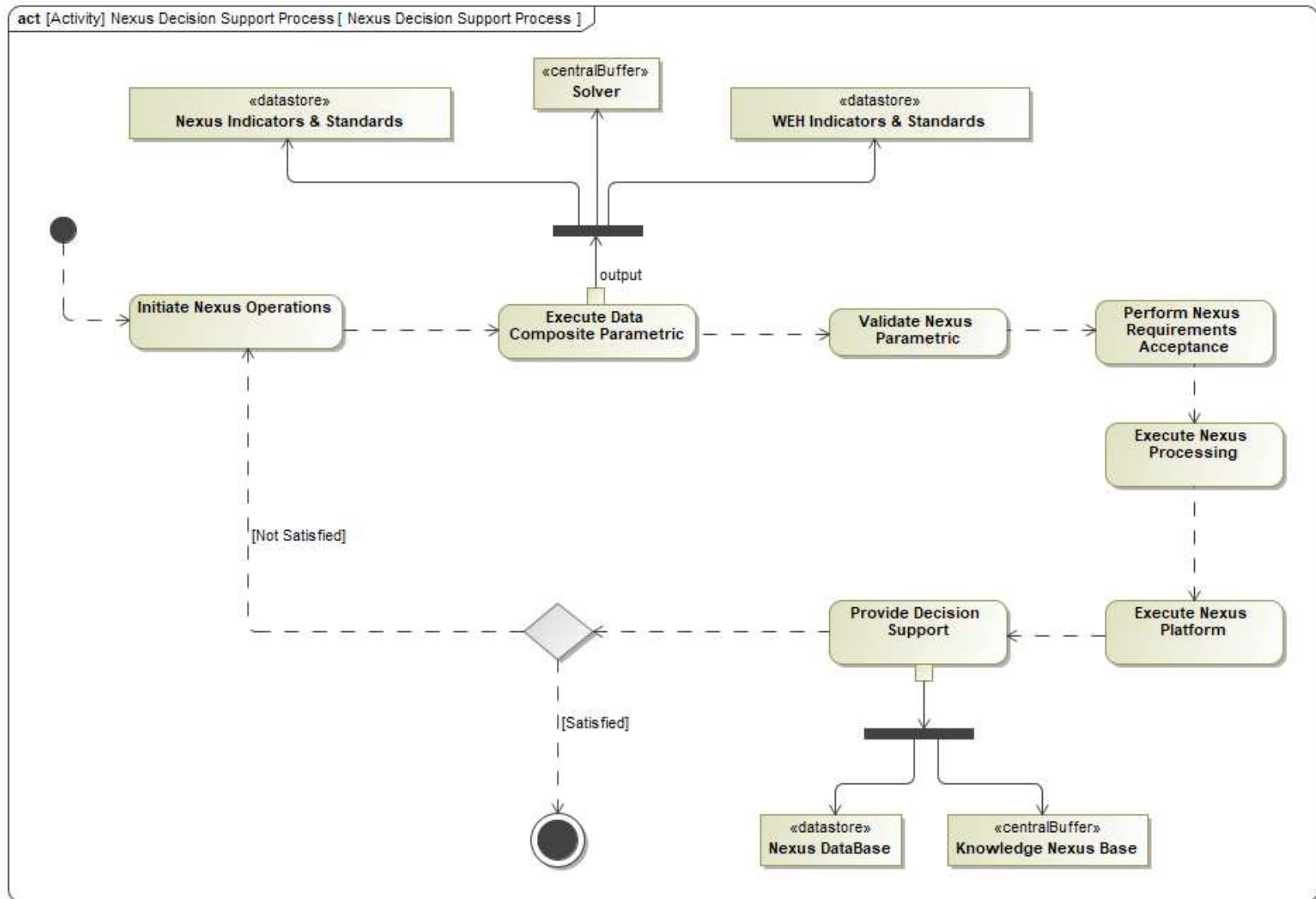


Figure 64: (idem 41) Activity Diagram for Nexus Decision Support Process (Adapted from [104])

APPENDIX F: Structured Interviews & Results

Below is an overview and the results of the structured individual interview to evaluate the proposed System and the Decision Framework based on the integration of water, energy, and housing (WEH Nexus) into the design of humanitarian settlements, compared to the standard UNHCR settlement design guidelines and standards.

STRUCTURED INDIVIDUAL INTERVIEWS:

A Decision-Making Framework for the Water-Energy-Housing Triple Nexus Integration in the Design of Humanitarian Settlements.

Anicet Adjahossou, Anicet.Adjahossou@colostate.edu
720-662-9129
PhD Candidate in Systems Engineering
September 18, 2023

 **WALTER SCOTT, JR.**
COLLEGE OF ENGINEERING
COLORADO STATE UNIVERSITY

 **SYSTEMS ENGINEERING**
COLORADO STATE UNIVERSITY

Content

1. Why a Structured Individual Interview?
 - Research Tasks to Answer
2. Individual Interview Structure
3. Interview Question Guide
4. Interview Analysis Approach
5. Framework Evaluation Methodology
6. Q-Statements
7. Q-Methodology & Q-Sorting Diagram

1. Why a Structured Individual Interview?

- **To evaluate the proposed model of Systems Engineering Decision Framework based on the integration of water, energy and housing (WEH Nexus) into the design of humanitarian settlements, compared to the standard UNHCR settlement design guidelines and the state of the art.**
- Structured interviews to interview individuals from UNHCR personnel and relevant experts who have knowledge about the area of research (humanitarian settlement data management) and can provide expert views and a perspective on it. Individual interviews are the most commonly used data collection strategy in qualitative research (Nunokoosing, 2005; Sandelowski, 2002). SAGE Publication: <https://doi.org/10.4135/9781452218403>

Research Tasks to Answer:

- Evaluate the operational effectiveness of the proposed decision-making framework compared to the UNHCR operational data use for settlement design and management approaches with data management Experts and settlement planners and users.
- Conduct a simulation analysis of the framework's application in an existing refugee settlement.
- Apply a Q-Methodology to evaluate the 39 Q-Statements about the operational effectiveness of the proposed framework.
- **Result:** An objective evaluation based on the expert judgment of the proposed nexus framework is achieved to shed light on its potential applications in UNHCR operations.
- **Method:** A structured face-to-face and/or Zoom interview completed with Q-Sorting procedure.

2. Individual Interview Structure

- In-person (primary) and/or virtual with UNHCR staffs: Water, Energy, Shelter technical experts, operational data managers and other settlement managers directly involved in the design and management of humanitarian settlement operations.
 - Size: 6 - 12 individual participants recommended. (The SAGE Handbook of Interview Research: The Complexity of the Craft).
- **Date:** October 2023
- **Duration:** 2-3 hours recommended (The SAGE Handbook of Interview Research: The Complexity of the Craft)
- Begin with a presentation of the research background and a demonstration/simulation of the proposed decision-making framework model focusing on the operational validity of integrating water, energy and housing to improve the design and management of humanitarian settlements.
 - Then, transition to interview questions.
 - Qualitative and quantitative methods will be applied simultaneously, with qualitative aims and objectives to exploring points of view, perspectives, suggestions, and the interaction with the participants and quantitative techniques (standard compliance, model parameterization, correlation and factor analysis). Qualitative and quantitative aspects are intermingled throughout the interview process.
- Record interview and take photos for follow-up analysis/interpretation.

3. Interview Question Guide (Adapted from Liamputtong, 2011, Box 5.1)

BACKGROUND	The UNHCR master plan approach to settlement planning provides a framework for the design of humanitarian settlements. It establishes a single vision of response aligned with national, sub-national and local development plans, and recognizes the contributions that humanitarian responses can make toward long-term development efforts. However, the current approach to site assessment and data collection (using various checklists and mapping templates) for settlement planning does not guarantee the ability to interrogate sectoral data and derive more comprehensive analyses for effective integration and sectoral data flow to streamline balanced decision-making.
INTRODUCTORY QUESTION	Please tell me in about 5 min your background and experience working with UNHCR on the use of operational in the design and/or management of humanitarian settlements.
TRANSITION QUESTION 1	Please tell me about the data management frameworks and/or methods you currently use and how you use them for the design and/or management of humanitarian settlements (or to inform for the design and management of humanitarian settlements).
TRANSITION QUESTION 2	Please tell me what kind of operational data (water, energy, housing) you are currently involved in and use, and which frameworks or tools for the design and/or management of humanitarian settlements.
TRANSITION QUESTION 3	Please tell me about the applications/decision-support tools used to execute the frameworks and/or methods described in the previous question.
TRANSITION DEMONSTRATION	Demonstrate and simulate the proposed Water-Energy-Housing Nexus Decision-Making Framework for the design and/or management of humanitarian settlements.
INTERVIEW QUESTIONS	<ol style="list-style-type: none"> 1. What are the primary challenges and constraints that UNHCR operations experience during the process of collecting, analyzing, storing, sharing, and managing operational data (water, energy, shelter) that hinder evidence-based decision-making for the design and management of humanitarian settlement based on the master planning approach? 2. How can operational data on water, energy, housing needs be intermingled, cross-referenced, and integrated in such a way that allows for increased intersectoral and comprehensive analysis? 3. Are there current shortfalls in integrating multisectoral data for decision-making during settlement design and development? 4. During the process of the design of a humanitarian settlement, how does UNHCR coordinate sectorial data collection/collation and sharing within different technical units, ei. Water, Energy, Shelter, which takes into account potential interactions between sectors? 5. What are the water parameters or properties that could influence the energy and housing sectors and vice versa to ensure an effective design of the humanitarian settlement? 6. What are the energy parameters or properties that could influence the water and housing sectors, and vice versa to ensure an effective design of the humanitarian settlement? 7. What are the shelter parameters or properties that could influence the water sector and vice versa to ensure an effective design and management of the humanitarian settlement? 8. How does UNHCR ensure an effective flow of data and sectoral requirements between the three sectors of water, energy, and housing, which could lead to the identification of multi-sectoral gaps for a more effective decision-making process when planning for humanitarian settlement? 9. What should UNHCR do to address issues concerning data access, and dissemination across various subsystems at different planning scales: macro, meso and micro levels? 10. In view of challenges and gaps thus noted, how do you think the proposed model framework for integrating water, energy and shelter data could contribute to improving decision-making and performance in the design and development of humanitarian settlements? 11. What barriers (i.e., technical, regulatory, financial, policy) would the proposed WEH nexus decision-making framework and application would you expect this to face? 12. What could be the cost / benefit for the implementation of the proposed WEH nexus decision-making framework?
SUMMARISING QUESTION	In summary, today we discussed a proposed water, energy and housing Decision-making Framework for the successful design of humanitarian settlements. Please share how this framework compares to current approach decision making and could be adopted and improved.
CONCLUDING QUESTION	Is there anything else we should have talked about today but didn't?

4. Interview Analysis Approach

The following questions will be answered to produce the results of the interview.

Component	Aspect for Analysis
What?	What aspects or issues raised on the proposed water, energy and housing (WEH) integrated decision framework that produced agreement?
	What statements seemed to evoke consensus?
	What statements seemed to raised confusions or contradictions?
	What common experiences or recommendations were expressed?
	Did the interview process generate new insights or precipitate an exchange of information from participants?
Who?	Who will benefit directly and indirectly from the application of the proposed integrated decision framework?
	Who could be the key decision-makers to facilitate the implementation of the proposed framework?
	Who has suggested or demonstrated aspects that differ too much or too little from the proposed framework or parameters that are considered?
How?	How did participants adhere to the solutions proposed by the WEH Decision Framework?
	How did participants respond to the ideas?
	How do participants get involved in implementing these proposed solutions?
	How do participants see the proposed framework being taken into account in future humanitarian settlement planning cycles?

5. Framework Evaluation Methodology

- Q-Methodology will be applied to investigate the objective views of participants involved in UNHCR operational data management and settlement design. (David Shemmings, Ingunn T. Ellingsen, Published: 2014, Sage Research Methods DOI: <https://doi.org/10.4135/9781452218403> - The SAGE Handbook of Interview Research: The Complexity of the Craft.
- Participants will be presented with a set of statements about the functionality of the proposed WEH framework, called the Q-set. Participants, called the P-set, will be asked to rank-order the statements from their technical knowledge, individual point of view, according to some preference, judgment or to the improvement of current UNHCR standards as practice, mostly using a quasi-normal distribution. By 'Q-sorting' the statements, the participants will provide their objective acknowledgement and professional perspectives.
- In the Q-Set of Statements, each statement is linked to one of the categories that leads to the conceptual decision-making framework.
- A Q-Set of 39 statements is considered for the interview. (Generally, a Q-Set of around 40 statements is considered satisfactory). The statements are formulated as answers to the question as "To what extent the proposed nexus framework responds to UNHCR needs in operational data management for the design of humanitarian settlements. (S. Watts, and P. Stenner, "Doing Q methodology: theory, method and interpretation," *Qualitative Research in Psychology*, vol. 2, no. 2, pp. 67-91, 2005).
- Firstly, the formulation of the 39 statements will be validated during a pilot interview phase with three respondents selected among UNHCR's technical experts.
- The individual participants will be asked to rank-order from "Strongly disagree" to "Strongly agree" on a Q-Sort Diagram as illustrated in Figure 1.

Q-Statements

Statement	Statement
Stratagems	1. The management of operational data for the various UNHCR technical units/sectors is highly decentralized.
Institutional & Technical Dimensions	2. The current UNHCR sectoral needs assessment approaches to technical data collection and analysis is highly decentralized. 3. There are an impressive number of sectoral data management systems, illustrating the solution-oriented mindset but within a decentralized approach. 4. UNHCR should make extensive use of operational data from the water, energy, and housing sectors to identify trends or to help predict future needs or changes in the behavior of populations that are served. 5. There is a requirement to connecting UNHCR's operational data and information management systems. 6. UNHCR technical units should avoid data warehouse approach which is a centralized repository for all integrated data sources. 7. UNHCR does not currently have integrated and operational sectoral data structures that could serve as a "rule book" for technical units/sectors and partners in the planning and management of humanitarian settlements.
Data Integration Issues	8. The roots cause of the current fragmented approaches is that data needs are defined (through need assessments), and tools and systems are developed by sectoral teams, sometimes for specific situations and operations. 9. The current fragmented approaches do not contribute to the improvement and efficiency of operational data collection, storage, and analysis, particularly for the three technical sectors of water, energy, and housing. 10. The development of an integrated technical wide rule book would significantly support the improvement of operational data quality overall for more sustainable humanitarian settlement development. 11. There is a crucial gap in terms of operational data integration for UNHCR to develop a system-vision of multi-sector data management to become more effective and efficient in generating useful information for decision-making, advocacy and demonstrating results. 12. To address the challenges, different options can be explored, such as setting up a data lake where raw data can be extracted from different systems. 13. The system approach and interoperability have not been taken into account within the settlement overall system. 14. All UNHCR technical units should implement system-thinking approach to data operations for settlement design.
Sustainability dimensions	15. Sectoral integrated data analysis and use lead to sustainability in the settlement design and development. 16. There are measurement indicators that will objectively support the integrated operational data management for humanitarian settlement design. 17. An integrated framework on sectoral data management sets the foundation for sustainable settlement design and development. 18. The current fragmented approaches in operational data management in water, energy and shelter sectors compromises the sustainability development of humanitarian settlement.
Humanitarian settlement	19. There are technical challenges in transforming operational data on water, energy, and shelter into added value for decision-making processes for the design of humanitarian settlements. 20. Sector data files and information products should be stored in a centralized location (databases) accessible to all UNHCR staff and/or partners who should have access to them when planning settlements. 21. The expected results of using operational settlement design are to harness existing data for deeper and more meaningful use, and to ensure consistency and quality across sectors. 22. An integrated technical wide rule book would result to better efficiencies in humanitarian settlement management.
System-based framework	23. The new framework sets the foundation for predictable and principled bi-sectoral data flows between UNHCR and settlement stakeholders it works with in compliance with humanitarian principles. 24. Data collection, storage, analysis and sharing systems can be improved through a system-based framework. 25. There should be a standardized organizational system for storing, sharing and analyzing operational data, and for comparing it with output or individual data. 26. An integrated technical wide rule book would set out the structures and processes. 27. An integrated system framework enables all the UNHCR technical units or sectors to apply more harmonious data management approaches. 28. The use of factual and operational data could be modeled in a system framework through Model-Based System Engineering (MSBE) approaches. 29. The use of a system framework through Model-Based System Engineering (MSBE) approaches will strengthen the three technical sectors of water, energy, and housing, and in general, in all sectors. 30. An integrated system framework enables all the UNHCR technical units or sectors to apply more harmonious data management approaches.
Partnership dimensions	31. Sharing and accessing operational data with UNHCR partners and stakeholders will be done through partnership more effectively. 32. Operational data from the water, energy and housing sectors should be linked to better quality data for all stakeholders. 33. An integrated technical wide rule book would ensure that the right data is always available and accessible to the appropriate audiences at the right times. 34. An integrated system framework will ensure consistency and quality across different sectors. 35. A system-based nexus decision-making framework for water, energy, and housing represents a partial response that will facilitate optimal use of multisectoral data.
Multi-sectoral approach	36. A multi-sector approach through system-based approach will systematize and ensure operational needs/data interoperability. 37. A multi-sector approach to data integration systems will improve operational performance. 38. The proposed system-based nexus decision-making framework for water, energy, and housing will facilitate a cross-sectoral analysis to the improvement of operational performances in humanitarian settlements. 39. Developing a system-based dataset will optimize the use of technical properties that integrate and aggregate data to build capacity and confidence around standards and evidence on displaced populations. 40. Investing in effective model-based system engineering solutions (EMBE) that connect data from different systems will improve cross-sectoral and comprehensive analysis of the situation and needs of people of concern to UNHCR. 41. There is requirement to improve data sharing and accessibility to all the humanitarian settlement's stakeholders to provide useful integrated data to the increasing number of stakeholders that are actively involved and working with humanitarian settlements. 42. It is important to adopt an inclusive approach to multisectoral data sharing that tracks how UNHCR uses and disseminates operational data to a wide range of stakeholders.

7. Q-Methodology & Q-Sort Diagram

Adapted from: D. Kumar and Z. Rahman, "Sustainability adoption through buyer supplier relationship across supply chain: A literature review and conceptual framework," International strategic management review, vol. 3, pp. 110-127, 2015.

As the nature of the interview is explorative, applying the Q-methodology would be meaningful and has shown its usability in the social complex context. (A.J.G. Silvius, and al. An investigation using Q-methodology," International Journal of Project Management, vol. 35, no. 6, pp. 1133-1150, 2017).

- Q-methodology identifies the participants' views on 39 statements formulated in the context of evaluating the proposed framework.
- The statements will be sent to the participants who will be asked to rank-order from "Strongly disagree" to "Strongly agree" on the Q-Sort diagram as illustrated in Figure 1, using a symmetrical diagram, as is normally preferred in Q-methodology.
- Q-Sort Grid Consisting of 39 spaces ranging from +4 (Most Agree) to -4 (Most Disagree) with a Center (0) for Statements that Are Neutral.
- Analysis will be conducted based on the Kaiser-Guttman criterion, significant loading factor and a less strict applied Humphey's rule.

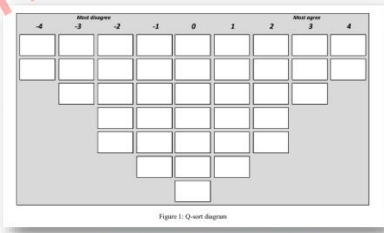


Image source: <https://www.sciencesphere.org/ijpm/archive/ijpm-0602.pdf>



Structured Individual Interviews Results

Structured Individual Interviews Results Analysis		
Group component	Aspects for analysis	Analysis Results
What?	What aspects or issues raised on the proposed water, energy, and housing integrated decision framework that produced agreement?	<ul style="list-style-type: none"> - Senior managers recognized the added value of the proposed Nexus Framework in terms of cost savings for UNHCR, and operational impacts optimization. - Need for generalization of the framework and its application to other crucial sectors such as nutrition, health, and education. - SME acknowledged automation of the framework will enhance prioritization process and data processing across the three sectors, more integrated and synchronized, thus improving the performance of current UNHCR systems. - Request to include the core indicators of SDGs 6, 7 and 11 to the links humanitarian aid and development. - Anticipate potential barriers that could hinder the implementation of the Framework with all indicators, as some countries restrict access to certain data or the regulation of sectors such as energy. - Issue of the platform manager's responsibilities was raised, with the recommendation that the manager to have capacities to guarantee consistent data quality assurance for the three sectors. - For the integrated system, it was suggested that civil society could be considered as a key component, in the Institutional or Populations sub-systems. - It was also suggested to specify at which stages the integrated system model could be applied and the framework implemented,

		<p>given that the different sectors do not have the same importance and funding.</p> <ul style="list-style-type: none"> - Need to execute a test or implement the Model and the Framework in Emergency, transitional, and protracted contexts to seek possible adaptation and areas for improvements.
	What statements seemed to evoke consensus?	<ul style="list-style-type: none"> - Recognition of the framework as an improved planning and anticipation tool in line with UNHCR's ongoing multi-sectoral alignment reforms. - Usefulness of the framework in the settlement transformation process with focus on system planning approach. - Shift toward more impactful integrated outcome-based solutions. - No similar in-house multisectoral integrated Framework exist and needs further piloting in real-humanitarian settlement contexts. - Addressing system approach in settlement planning from the beginning as an improvement of the current master planning approach to settlement. - How to ensure monitoring of data and measurement of indicator performance.
	What statements seemed to raise confusions or contradictions?	<ul style="list-style-type: none"> - Some confusion emerged, such as how to ensure intra-operability among the Framework sectors? - And, how to achieve real interconnection with other sectors whose implementation uses the cash transfer method. - How to make both sectoral and composite data work in the unified database (integrated platform), and how to ensure that they are shared in accordance with policies and the needs of each stakeholder. - Challenges in terms of capacity to acquire the software to make the model and Framework work permanently in the Organizations. - Some contradictions appeared in the governance of the Framework on the need to identify who should authorize execution or implementation, given the overly regular turnover in humanitarian contexts. Additionally, how to connect or link the Framework with existing in-house Databases and with DIMA.
	What common experiences or recommendations were expressed?	<ul style="list-style-type: none"> - Consider the possibility of including "Industrial" as a component of Urban Planning subsystem. - Introduce the Model and Framework to UNHCR/DRS as an Organizational planning instrument for its standardization and ensuring UNHCR standards well incorporated and related-SOP. - Establish links and standardize common experiences with other agencies that share data with UNHCR. Other agencies adopting the same or a similar Framework will enable integrated Inter-Agency data exchanges. - Ensure better performance of the framework by establishing a consensus with the population biometric database and exclude non-shareable private information.
	Did the interview process generate new insights or precipitate an exchange of	Yes. The participants better understood the proposed framework and began to discuss how to harmonize with existing data collection tools and template, and to minimize human interferences. Other points are how to capture water and energy quality measurement indicators to

	information from participants?	have complete information on those sectors. In addition, concerns were raised as to how the proposed Framework could influence the change in the UNHCR staffing with regard to the three sectors that are combined into "one" from settlement management perspective. The majority calls for its implementation in the three humanitarian contexts of emergency, transition, water and stability, to facilitate rapid decision-making processes.
Who?	Who will benefit directly and indirectly from the application of the proposed integrated decision framework?	Stakeholders include Operations departments, who will benefit from the budgetary advantages of implementation; data managers, who will find it easier to process and share data in real-time; and external relations units, who will have access to information useful for advocacy.
	Who could be the key decision-makers to facilitate the implementation of the proposed framework?	Governments entity in charge of settlement management and UNHCR Seniors managers from Country Operations.
	Who has suggested or demonstrated aspects that differ too much or too little from the proposed framework or parameters that are considered?	Senior managers and two other participants recommended that the Model and Framework be presented and demonstrated to other Sections of UNHCR and to certain external stakeholders to take their opinions into account, which will facilitate implementation. The representative of the government side suggested that Country technical services, such as water, energy, and housing, could also be consulted to reach a broader consensus. Given that "often people fear change" and some organizations dislike sharing their data. Bilateral discussions are agreed to be organized if necessary.
How?	How did participants adhere to the solutions proposed by the WEH Decision Framework?	The individual interviews and, above all, the live demonstration of how the Model and Framework work, generated widespread acceptance among participants as a solution to the challenges currently faced by operations with ad hoc and parallel management approaches. They moderately adhered to the issues for discussion and was able to discuss each issue at varying lengths.
	How did participants respond to the ideas?	Participants positively responded to questions during the interviews and demo and were curious to see results and constructively contributed to the discussions and provided useful feedbacks.
	How do participants get involved in implementing these proposed solutions?	Expectations have been raised regarding implementing the Framework, which promises to resolve data processing difficulties. Given that many tools are currently being experimented with, with no similar results.
	How do participants see the proposed framework being considered in future humanitarian settlement planning cycles?	Concerns and comments formulated during the interviews will be considered in the implementation phase of the Framework, with prior agreement from Country Operations. Results and feedback will be used to generalize the Framework in humanitarian cycle planning.

APPENDIX G: Q-Statement Overview

Q-Statements		
Categories	id	Statements
Institutional & Technical dimensions	1	Operational data management for UNHCR's various technical sectors is highly decentralized.
	2	UNHCR's current sectoral needs assessment approach to technical data collection and analysis is decentralized.
	3	Sector-specific data management systems exist, illustrating the solution-oriented mindset, but with a decentralized approach.
	4	UNHCR should make comprehensive use of operational data from the water, energy and housing sectors to better help forecast needs and changes.
	5	There is a requirement to connecting UNHCR's operational data and information management systems.
	6	UNHCR's technical units should avoid the data warehouse approach, which is a centralized repository of data.
	7	UNHCR does not currently have integrated and operational sectoral data structures.
Data integration issues	8	The root causes of current fragmented approaches is that data requirements are defined through sector-specific needs assessments, sometimes for specific situations and operations.
	9	Current fragmented approaches do not contribute to improved and efficient management of operational data for water, energy and housing.
	10	The development of a set of integrated technical rules would be more expensive for UNHCR operations.
	11	The integration of operational data enables the production of useful information for decision-making, advocacy and results.
	12	To address the challenges, different options can be explored, such as setting up a data lake where raw data can be extracted from different systems.
	13	The system's approach and data interoperability may be difficult to apply to all UNHCR operations.
Sustainability dimensions	14	All UNHCR technical units should implement system-thinking approach for settlement design.
	15	The integration of sectoral data does not always ensure the sustainability of human settlements.
	16	The integration of operational data should be supported by measurement indicators.
	17	An integrated sector data management framework lays the foundations for the sustainable development of humanitarian settlements.
Humanitarian settlement	18	Current fragmented approaches in the water, energy and shelter sectors are implemented by non-experts.
	19	The transformation of operational data for water, energy, and housing does not provide added value for decision-making processes concerning the design of humanitarian settlements.
	20	Sectoral data and information products should be accessible to all partners.
	21	The results expected from the use of integrated data guarantee consistency and quality in all sectors.
	22	An integrated technical wide rule book would result to better efficiencies in humanitarian settlement
System-based framework	23	The new framework will reinforce UNHCR's principles and compliance with humanitarian principles.
	24	Data collection, storage, analysis and sharing systems can be improved through a system-based framework.
	25	The integrated system for sharing and analyzing operational data enables rapid decision-making.
	26	An integrated technical-wide rule book would set out protocols for better structure processes.
	27	A systemic framework enables all UNHCR technical units to apply harmonized approaches to data use and management.
	28	The use of factual and operational data could be modeled in a system framework through Model-Based System Engineering (MSBE) approach..
	29	The use of a systems framework through model-based systems engineering (MBSE) approaches could reduce the human factor.
	30	An integrated system framework does not guarantee that all data parameters are taken into account.
Partnership dimensions	31	Sharing and accessing operational data with UNHCR partners and stakeholders can be done more effectively.
	32	Good knowledge and use of water, energy and housing data parameters are very useful for improving population quality.
	33	All humanitarian related operational data should be integrated and accessible to the appropriate audiences at the right times.
	34	There is no breach of confidentiality in the operational data of the three Nexus sectors.
	35	A system-based nexus decision-making framework for water, energy, and housing represents a partial solution that will facilitate the optimal use of multi-sector data.
Multi-sectoral approach	36	This approach will encourage other partners and stakeholders to share their data on water, energy & housing.
	37	A systems approach to data integration will improve performance in achieving sustainable development goals in these three sectors.
	38	The proposed framework will enhance dynamic cross-cutting impact analysis.
	39	The proposed framework would build capacity and confidence in standards and data relating to displaced populations.

Instructions:

For this second stage of the survey (Q methodology), you are presented with a series of 39 Statements (Q-Statements) about the Nexus Framework.

Please use the 39 blank cells to rank the 39 Q statements from "Most Agree" to "Most Disagree," according to your individual point of view, your personal perspective based on your experiences, and/or your judgment about them, mainly using a quasi-normal distribution.

By sorting the statements at the end, all 39 statements will be inserted into the 39 blank cells, in the form of a normal distribution. The resulting data matrix will be a normal distribution curve reflecting your sorting arrangements for later analysis.

Q-Sort Grid for Respondents

	Disagree			Neutral		Agree			
Raw scores	(-4) Most	(-3)	(-2)	(-1) Least	(0) Neutral	(+1) Least	(+2)	(+3)	(+4) Most
Statement numbers									

APPENDIX H: List of Interviewed Participants

num	Title/Sector	Location	Agency / Organization	Date
1	Operations Management	Mali	UNHCR	10/26/2023
2	Water	Kenya	UNHCR	11/16/2023
3	Settlement Planning	Colombia, Bogota	UNHCR	10/12/2023
4	Nexus	Jordan, AMMAN	UNHCR	10/20/2023
5	Water	Mali	UNICEF	11/22/2023
6	Data Management	Mali	UNHCR	11/18/2023
7	Infrastructure	Mali	International Organization	11/11/2023
8	Settlement Planning	RCA	UNHCR	11/15/2023
9	Human Settlement	HQ Geneva	UNHCR	10/13/2023
10	Settlement Planning	Nairobi, Kenya	UN-Habitat	11/20/2023
11	Energy	Kenya	UNHCR	11/8/2023
12	Housing	Nigeria	UNHCR	11/17/2023
13	Housing	Afghanistan	UNHCR	11/14/2023
14	Operations	Ghana	UNHCR	11/18/2023
15	Housing	Mali	UNHCR	11/21/2023
16	Water & Housing	Senegal	ECHO	11/23/2023
17	Senior Management	DRC	UNHCR	11/18/2023
18	Settlement Management	Mali	Government	11/16/2023
19	Data Management	Mali	UNHCR	11/18/2023
20	Data Management	Mali	UNHCR	11/18/2023

LIST OF ABBREVIATIONS

DEEP	Data Entry and Exploration Platform
DIMA	Data and Identity Management Analysis
DRS	Division of Resilience and Solutions
IGO	International Organization
IHSS	Integrated Human Settlement System
IMO	Information Management Officer
INCOSE	International Council of Systems Engineering
JDC	Joint Data Center
KISED P	Kalobeyei Integrated Socio-Economic Development Plan
MBSE	Model-Based Systems Engineering
MDI	Matrix Direct Influence
MEI	Moving Energy Initiative
MICMAC	Cross Impact Matrix Multiplication Applied to Classification
NGO	Non-Governmental Organization
OECD	Organization for Economic Cooperation and Development
OMG	Object Management Group
OO	Object Oriented
OOSEM	Object-Oriented Systems Engineering Method
OPM	Object Process Method
RBM	Result-Based Management
RUP SE	Rational Unified Process for Systems Engineering
SCIA	System Capacity Interdependence Analysis

SDG	Sustainable Development Goals
SE	Systems Engineering
SME	Subject Matter Expert
SMEs	Small and Medium Enterprises
SOP	Standard Operating Procedures
SSE	Social Systems Engineering
SysML	Systems Modeling Language
TNF	Triple Nexus Framework
TWG	Thematic Working Group
UML	Unified Modeling Language
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
WASH	Water, Sanitation and Hygiene
WEH	Water, Energy, Housing
WFP	World Food Program