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Model-Based Systems Engineering Approach to Design a Human Settlement to Better Serve Displaced People

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Abstract

The challenge of transitioning from temporary humanitarian settlements to more sustainable human settlements is due to a significant increase in the number of forcibly displaced people over recent decades, difficulties in providing social services that meet the required standards, and the prolongation of emergencies. Despite this challenging context, short-term considerations continue to guide their planning and management rather than more integrated, longer-term perspectives, thus preventing viable, sustainable development. Over the years, the design of humanitarian settlements has not been adapted to local contexts and perspectives, nor to the dynamics of urbanization and population growth and data. In addition, the current approach to temporary settlement harms the environment and can strain limited resources. Inefficient land use and ad hoc development models have compounded difficulties and generated new challenges. As a result, living conditions in settlements have deteriorated over the last few decades and continue to pose new challenges. The stakes are such that major shortcomings have emerged along the way, leading to disruption, budget overruns in a context marked by a steady decline in funding. However, some attempts have been made to shift towards more sustainable approaches, but these have mainly focused on vague, sector-oriented themes, failing to consider systematic and integration views. This study is a contribution in addressing these shortcomings by designing a model-driving solution, emphasizing an integrated system conceptualized as a system of systems. This paper proposes a new methodology for designing an integrated and sustainable human settlement model, based on Model-Based Systems Engineering and a Systems Modeling Language to provide valuable insights toward sustainable solutions for displaced populations aligning with the United Nations 2030 agenda for sustainable development.

Keywords

Humanitarian Settlement, Human Settlement, Sustainability, Systems Engineering, Model-Based Systems Engineering, Systems Modeling Language

1. Introduction

A humanitarian settlement is generally defined as a geographically habitable space that provides living conditions and influences the well-being of displaced populations. But over the years, it has been observed that their planning and management have often not been adapted to local contexts and the prospects of host communities, nor to demands and growth of populations, which are highly problematic in host countries. Furthermore, the current approach to temporary settlement has negatively impacted the environment, and the poorly planned conditions have put significant strain on scarce resources such as water, energy, building materials, forest, and vegetation cover. All these factors call for a change in the approaches and methods to encourage greater integration of elements and communities.

In February 2023, the United Nations High Commissioner for Refugees (UNHCR) estimated the total number of displaced populations would reach more than 117 million, up from 103 million in 2022. Less than 1% can return home, a figure that has more than doubled over the past two decades [1]. While the average lifespan of a refugee settlement is between 17 and 26 years [2], the UN reported that globally over 10 million displaced people are established in developing countries, and many are self-settled among host communities, sharing overcrowded accommodations in substandard or uncompleted settlements. The UN estimated about 70% of settlements are informal with a lack of secure tenure, access to basic services, limited resources, and inadequate planning options, often located in geographically and environmentally hazardous areas [3]. Although humanitarian settlements are seen as landlocked territories, they depend on and rely on complex governance bodies, which function like a city [4]. Consequently, they need to be approached as a holistic system made up of many interdependent elements. All planning scenarios must consider the interlinkages between these elements, so that they function holistically as a single entity. As reported by the World Bank [5], most humanitarian settlements are located in countries confronted with rapid urbanization and excessive pressure on existing resources, with enormous stresses on urban quality of life [6]. According to World Bank Group [5], most human settlements hosting forcibly displaced communities are in developing countries lacking basic infrastructure and urban planning fundamentals [7]. Consequently, over 30% of humanitarian settlements located in rural or peripheral areas are experiencing massive urbanization, and the transition that is taking place will undoubtedly affect their development. In addition, the change in population dynamics and the accelerated urbanization in the rural refugee-hosting regions will pose considerable stresses on human settlements and hinder their sustainable and socio-economic prosperity. As a result, new approaches to settlement development in the years to come will have to anticipate future change and gradually adapt to integrated urban planning fundamentals inspired by systems approaches [8].

Tackling the same problematic, Ian Douglas [9] pointed out that human settlements form an environment that provides residents with amenities and quality of life. But it's also a source of pressure on the natural environment where activities draw on resources and materials transformed into products for consumption. Understanding how human settlements and the built capital interact is fundamental to ensuring their sustainable development [10]. Hence, a human settlement can be seen as a conventional city with complex socio-technical entities, and it would be obvious from the principle of superimposed structures that the concept of a sustainable human settlement has similar complexities to those of a conventional city. But it's worth noting that these analogous relative complexities have a distinctive feature, namely the "humanitarian" reference, which specifies the centrality of humanitarian principles involving the international community as stakeholder and decision-maker.

This paper proposes a typical human settlement system model composed of sub-systems that process data resulting from different activities and services. This work defines and conceptualizes an integrated and sustainable human settlement system as a complex techno-social system of systems, comprising key subsystems that are all interdependent and interrelated. To function as a system, all the subsystems are integrated through a unified platform that consolidates and gathers data to be accessible to all the system's stakeholders.

To guarantee the sustainability of a human settlement system, it is required to plan, design, develop, and manage it as an integrated system that ensures that all subsystems remain interconnected, interdependent, and function as a whole. But to achieve this vision, this work argues that the system's capacity to seamlessly capture, integrate, and disseminate data between subsystems could be a starting point for realizing the sustainability sought.

2. Literature Review

Humanitarian settlements have existed since the emergence of population displacements. The emergence of humanitarian settlements has therefore been associated with forced displacement for decades. Since then, those settlements were developed as temporary accommodations because refugees would return to their countries of origin after a limited period. The main objective has been the creation of temporary settlements [11] to accommodate displaced people who are seeking international protection. The literature review reveals that those temporary settlements were initially spread in some thirty countries worldwide with basic infrastructure. Some have been in existence for over 50 years, as evidenced by Palestinian camps established in the late 1940s. The Anthropologist Michel Agier estimated that 15 million people worldwide were living in humanitarian camps or settlements in 2014 [12]. In his study, Michel Agier critically pointed out that the "camp form" refers to three main characteristics: exceptionality, extraterritoriality, and exclusion, since they are mostly densely populated, not originally conceived as a city integrated into the host territory, either spatially or politically, with inhabitants "excluded" from the local administration. To avoid perpetuating the presence of displaced people in the host territory, settlements are often developed and maintained in a "temporary" status, even when they have existed for several years. This is the case, for example, of Zaatari settlement in a desert area, created in 2011 in Jordan to accommodate Syrian refugees, and which, by its size, is the fifth largest city in Jordan. Although, according to UNHCR's emergency handbook [13], the selection of settlement sites is a critical factor in the capacity to provide a safe and healthy environment, in most cases, they fail to meet minimum standards, often resulting in pendulum movements, unnecessary loss of resources and negative consequences. More importantly, establishing humanitarian settlements requires significant investment in infrastructure and basic service, and maintenance costs are considerable. One of the most striking examples is the Dadaab refugee camp in Kenya, Kenya's tenth largest city by population, with 233,828 refugees [14] as of 31 January 2023. Others with sub-standards figures and higher population density, the Kakuma refugee camp in Kenya, for instance, in 2020, had a density of more than 10,000 refugees per square kilometer [15], and Zaatari camp in Jordan, a density of 24,212 refugees per square kilometer [16]. Whatever the location and status of these settlements, the common denominator is to be providing a living space in compliance with humanitarian principles and local regulations. From his side to highlight the link between needs and resources, the United Nations High Commissioner for Refugee defines a refugee settlement [17] as "*a structured landscape of a territory that takes into 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*". As such, the settlement addresses the community's needs, including service provision and socio-economic and cultural dynamics. From this definition, one can understand that the planning and development of a refugee settlement should consider the dynamics and the needs of refugees. In a similar vein, the United Nations Human Settlements Programme [18] considers a human settlement "*an improvement of the quality of life of human beings, and it must facilitate the rapid and continuous improvement in the quality of life of all people, beginning with the satisfaction of the basic needs of food, shelter, clean water, employment, health, education, and social security without any discrimination* …". On the other hand, the Organization for economic cooperation and development (OECD)[1] defines a human settlement concept as "*an integrative concept that comprises physical components of shelter and infrastructure, and services to which the physical elements provide support community services*

[1]Glossary of statistical terms—Organization for Economic Co-operation and Development—OECD, 2007.

such as education, health, culture, welfare, recreation, and nutrition".

In short, until now, a humanitarian settlement has been seen as an isolated assemblage of things created by haphazard urban planning principles. The literature review shows that a humanitarian settlement is first and foremost a human settlement that functions and is developed for displaced people. Throughout this work, we will refer to the human settlement as a techno-social system, and to the application of systems engineering methods to explore the dynamics associated with the various components and to determine the interdependencies so sought-after for long-term viability and prosperity.

3. Methodology

This work applies Systems Engineering (SE) method to present a conceptual model of an integrated human settlement system. To this end, Model-Based Systems Engineering (MBSE) and Systems Modeling Language (SysML) are used as one of most appropriate applications capable of capturing the complexities of such a techno-social system and modeling it as an integrated, holistic system. Previous studies have concluded that MSBE approach offers proven advantages and is ideally suited to realizing and managing the complexities of human settlement systems to overcome the challenges of fragmentation as being experienced in practice today. This work adopts this methodology as capable of realizing a systematic view of a typical human settlement system from a meaningful operational data processing perspective through an integrated standard platform. To achieve this, this paper presents a sequenced approach that has enabled the conceptualization and the development of a typical integrated human settlement using systems engineering applications and research efforts.

4. Research Results

4.1. Definition of the Integrated Human Settlement Concept

In recent years, the concept of integrated, sustainable human settlement has come to the fore. It is rapidly gaining momentum on the agenda of humanitarian community as one of the promising solutions to the challenges facing humanitarian operations worldwide. However, because of its complexity, the concept still has no universally accepted definition. An in-depth analysis of existing attempts led to the adoption of a harmonized concept of an integrated human settlement in the context of this work. A definition of the integrated human settlement concept is based on broader dimensions, with a dominant view that displaced people would constitute a central element. Cognizant of the importance of the interconnections between the elements and components of a such a system, which would function effectively through the flow of data as the main driving factor, the various elements represent fundamental pillars whose consideration is crucial. By correlating different thematic definitions, this paper defines that the concept of an integrated human settlement would achieve the following three objectives:

- seamless integration of all components into a single system that functions as an entity.
- effective interconnection between components to produce collective results of high performance.
- meaningful data flow via a single data platform for efficient and uninterrupted services.

Thus, the concept focuses primarily on the meaningful processing of data between elements or subsystems, and on the capacity to provide efficient, uninterrupted services to displaced populations. In the light of this, this work defines as follows: "*An integrated human settlement is a system of systems derived from stakeholder requirements that process input-data from all subsystems to work together on an integrated platform, to enable the production of an efficient, uninterrupted flow of data and information, and the services required in real-time to serve displaced populations better*".

4.2. Representation of a Typical Integrated Human Settlement System

An integrated human settlement concept is a system of systems derived from stakeholder requirements, which is integrated with its subsystems working together on a single platform to produce meaningful data and information required in real time. As such, the conceptualization represents a system of systems composed of six fundamentally interrelated and interdependent subsystems. Figure 1 represents the proposed integrated human settlement system and the critical subsystems identified by the present work.

In the context of this work, analysis shows that an integrated human settlement is sustainable when it is composed of at least the six fully integrated subsystems. This dimension becomes evident when the six subsystems are well-linked and fully interdependent. However, in the process of developing human settlements, and particularly in the humanitarian context, which is all too often underpinned by phases of emergency, transition, and stabilization, it is obvious that the six subsystems cannot be built at the same time, at the same period and with the same levels of maturity. In this case, the actual scale of integration can be gradual and staggered. In this way, certain subsystems can be integrated to respond more quickly to specific services, and so on. Consequently, this sequential evolution in the development of human settlements requires the recognition of different scales of integration, from the lowest to the highest.

The definition of an integrated human settlement concept with its six subsystems illustrates the complexity, multidimensionality, and socio-technical potential of such a system. This system includes multi-physical, technical, social, economic, environmental, and regulatory domains, and the population who makes decisions and consumes various products and services. Based on this, this work considers that a truly integrated human settlement is one that performs well in all six dimensions of integration, namely urban planning and infrastructure, institutions and governance, social and integrated services, economy and finance,

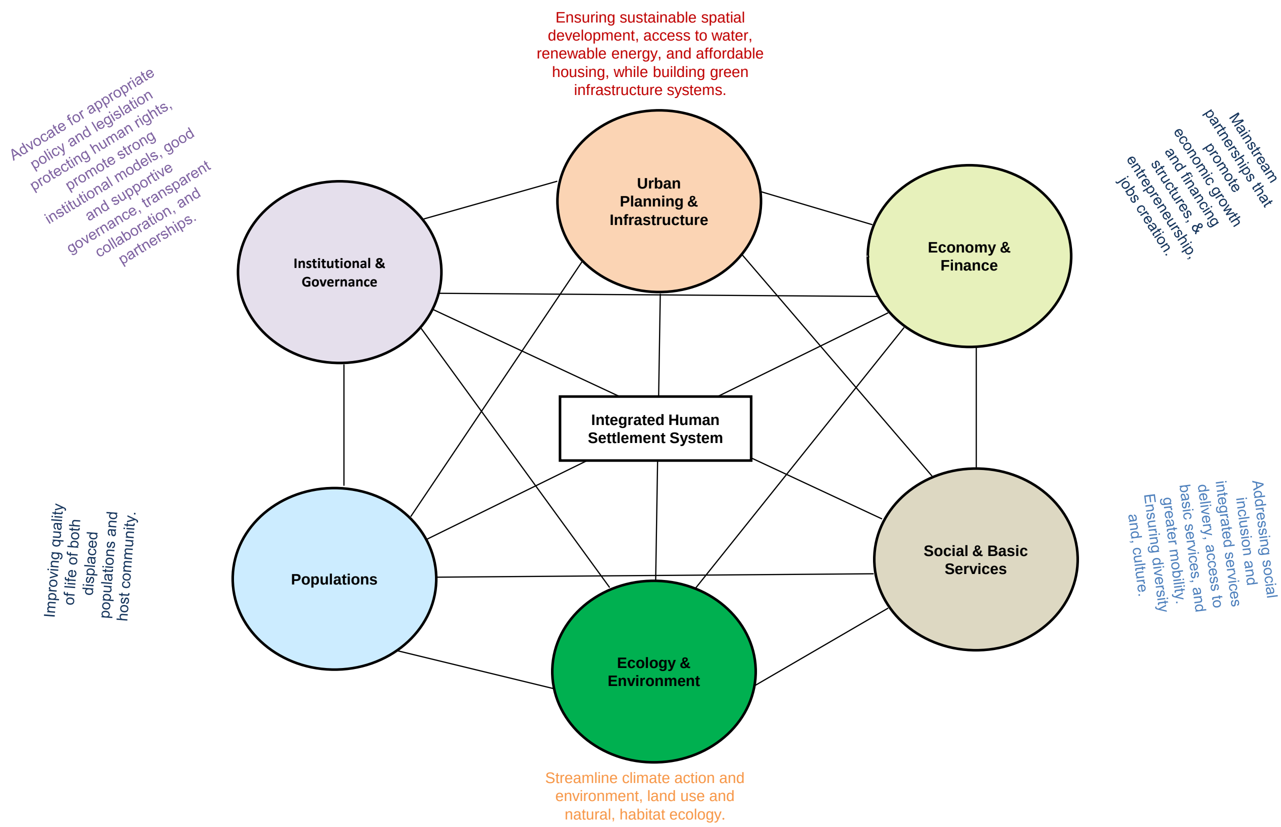

Figure 1. Representation of subsystems of the integrated human settlement system.

ecology and environment, and populations, interacting internally and with the external environment. Therefore, a human settlement is integrated if it is designed and well-planned as a system and fully equipped with key subsystems that provide the required services, including the capacity to command and control the processing of a stream of operational data that populations consume. For this work, a human settlement is considered integrated if it is made up of the following six subsystems: 1) Urban Planning and Infrastructure development; 2) Institutions and Governance; 3) Social and Services Delivery; 4) Economy and Finance; 5) Ecology and Environment, and 6) Populations, working together on an integrated platform. This platform would be the catalyst for streamlining and improving integration at all levels and data processing, enabling the system to be effective and efficient across the six integrated sub-systems.

4.3. Modelling the Integrated Human Settlement System

The system model of an integrated human settlement shows that the six subsystems and their components work together, focusing on the processing of operational data generated by the system for sustainability planning and management. To further illustrate the operational view of the system, SysML is used to clearly define the logical structure and architecture of the system, as well as the appropriate links between all the sub-systems and their components. Finally, the system thus developed is executed and simulated under specific conditions for analysis. The modeling process is carried out through the creation of diagrams that present the levels of detail required to facilitate interconnections between all subsystems and their components. It is noteworthy that this process is used to construct the diagrams required for this study. Figure 2 shows the overall structure of the model, with the six subsystems represented by blocks that are linked

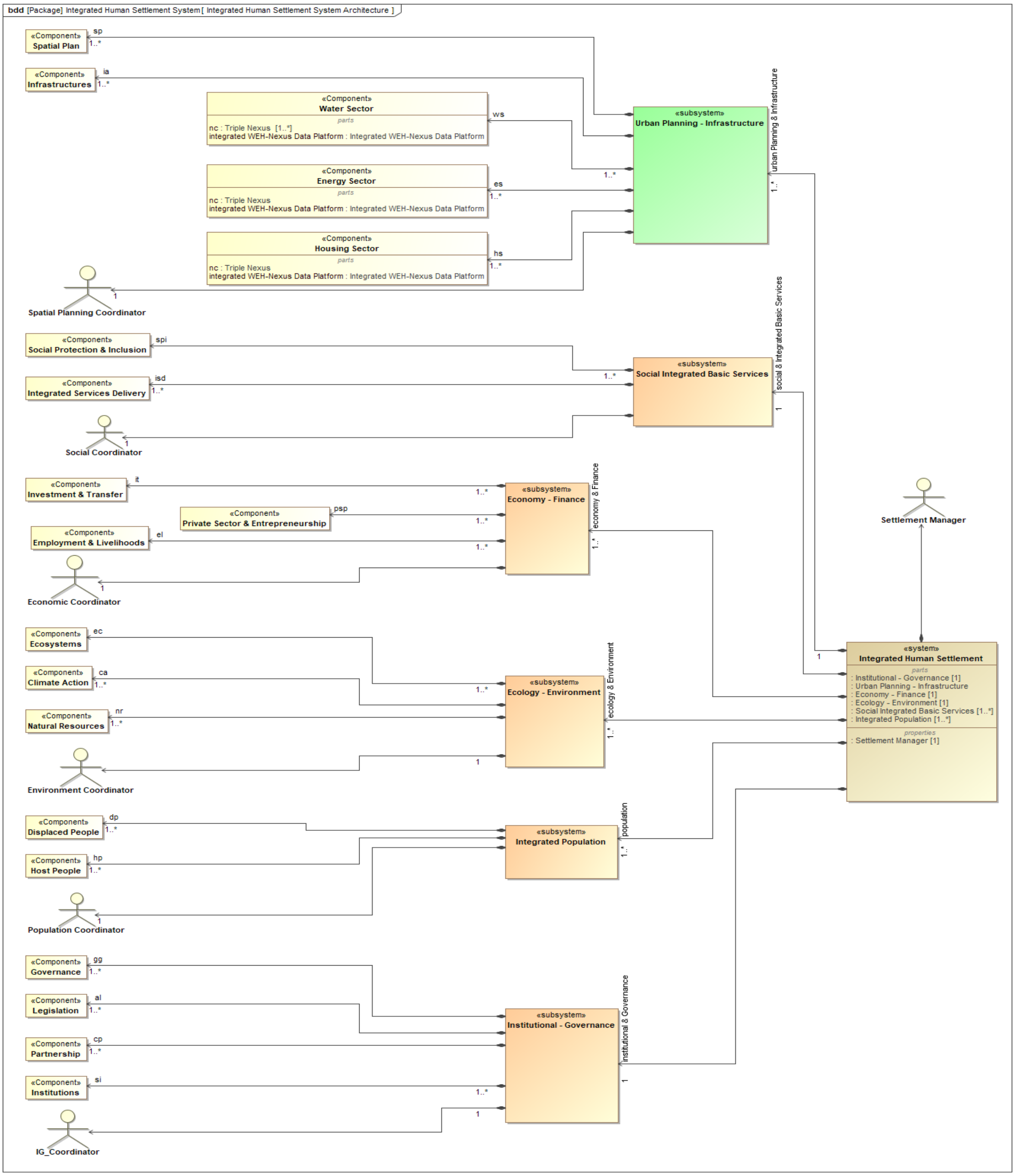

Figure 2. Simplified SysML integrated human settlement system structure.

together and converge their processed data into an integrated database. The structure presents the subsystems as parts of the human settlement system, in which data blocks use data produced by different sources, and process them into useful, standards-compliant data.

In terms of functionality, data processing takes place in three main stages. In the first stage, data is collected from a variety of sources (including from needs assessments), and then is transferred into the various sub-systems. Data collected is verified by experts from each sector and then stored on the individual data platform. In the second step, data produced after the verification process is processed at this level through prioritization and integration procedures from an integrated composite data perspective, to produce a meaningful and useful integrated composite data set for multi-sector programming. Data processing at the data block level produces "operationally useful" quality data and "operationally useful" composite data. In the final stage, the processing of the different types of data will produce corresponding information products at the information block level linked to subsystems for automatic updates as it may require. At the platform level, data, and information optionally produced are made available to users and authorized consumers.

The integrated human settlement model is designed with all the six required sub-systems and their respective components. The six sub-systems are: Urban Planning & Infrastructure; Institutional & Governance; Social Services; Economy & Finance; Ecology & Environment; Populations, represented respectively by "sub-system" blocks of the system, which is represented by the "system" block. The sub-systems' components are represented in the rights of each sub-system by "components block". They are directly connected to each sub-system using a "Directed Composition" association connection (composition with navigability arrowhead). The "Directed Composition" (composition with navigability arrowhead)-link shows the Part or Blocks and is uniquely owned by the higher-level Block.

As detailed in **Figure 2**, components with composite association links to sub-systems establish direct relationships with them with specific roles in data production process and should be understood as follows:

- Urban Planning & Infrastructure subsystem has five components (Spatial Plan, Infrastructure, Water sector, Energy sector, Housing sector).
- Institutional has four components (Legislation, Institutions, Governance, and Partnership).
- Social and Services with two components (Social and Services delivery).
- Economy has three components (Investment, Employment, and Entrepreneurship).
- Environment has three components (Ecosystems, Climate, and Natural resources).
- Populations with two components (displaced people and host people).

4.4. State Machine High-Level Behavioral Diagram

A SysML State Machine diagram (Stm) is created to perform the system behavior analysis, as shown in **Figure 3**. The Stm diagram specifies system states, which are presented as a sequence of actions and events that the system undergoes, from the creation of the system's data platform to the sharing of data

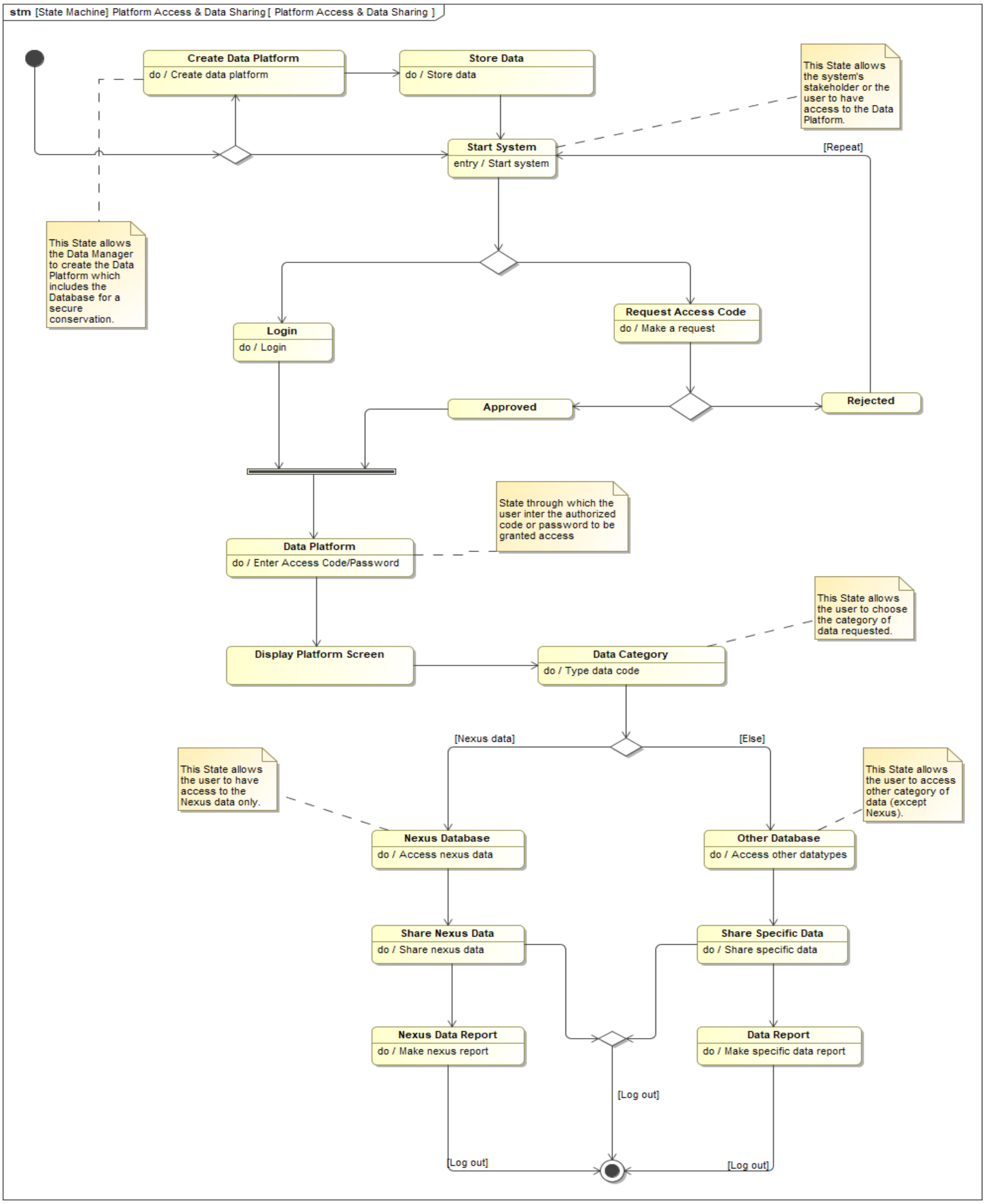

Figure 3. SysML high-level state machine diagram.

throughout its lifetime without deviating from the requirements. The preliminary stages of data collection at subsystem level and their entry into the platform fall outside the scope of this work. On the other hand, data processing, analysis, and simulation processes are illustrated by other behavioral diagrams.

Figure 3 presents the system's State machine diagram, which defines how system states change when transitions are triggered. The diagram represents system behavior in terms of transitions between states that are triggered by events. In this way, the system can reject or approve a request for access to the data platform when the user does not meet the prerequisites. Also, the system can guide the user to the category of data he is looking for, which is executed 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 integrated subsystems through the data integration process, where it can be accessed and taken by stakeholders or users. The State Machine diagram illustrates the user's decision and the data platform's behavior in the states it passes through when subjected to user activities. It also shows the high-level states where the main functions focus and conditions for secure access to the platform.

4.5. Integrated Data Platform Diagram

The system model presents the integrated data platform (see **Figure 4**), which receives all data from the components and subsystems, and stores in a secure and accessible database. All data is generated and processed at subsystem level. The resulting data and information are then stored at the integrated data and information platform level, where it is consumed or shared among the humanitarian community in accordance with agreed-upon protocols. The integrated data platform of the human settlement system is designed to focus on the processing of quality data and sharing between the six integrated subsystems as a method for an operational data integration perspective.

4.6. Logical System Architecture

A detailed logical architecture is presented in the form of a structural diagram of the human settlement system designed based on the MBSE methodology, with the six subsystems described above and illustrated in **Figure 5**. The logical architecture of the integrated human settlement system 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 linked to the subsystems on which they respectively depend.

4.7. Model Validation

To gather the views of practitioners and experts in the field of settlement planning and operationalization, a series of structured interviews is being organized between October and September 2023 in two forms: in person and online via Zooms calls. Structured face-to-face interviews with a group of twenty participants are conducted to evaluate the new system and present this proposal to an audience of practitioners and decision-makers for their criticism and comments, which would help build consensus on operationalization. During the interviews, participants received background information on the system model through interactive and open discussions. For the analysis of the results, the researcher uses Liamputtong's 12 aspects of interaction [19] to analyze the participants' responses. With regard to the "What" component, some participants recognized the added value of the proposed system in terms of benefits that will have a significant impact on the programming of activities. However, these results will only be meaningful once the project has been monitored and the costs and benefits

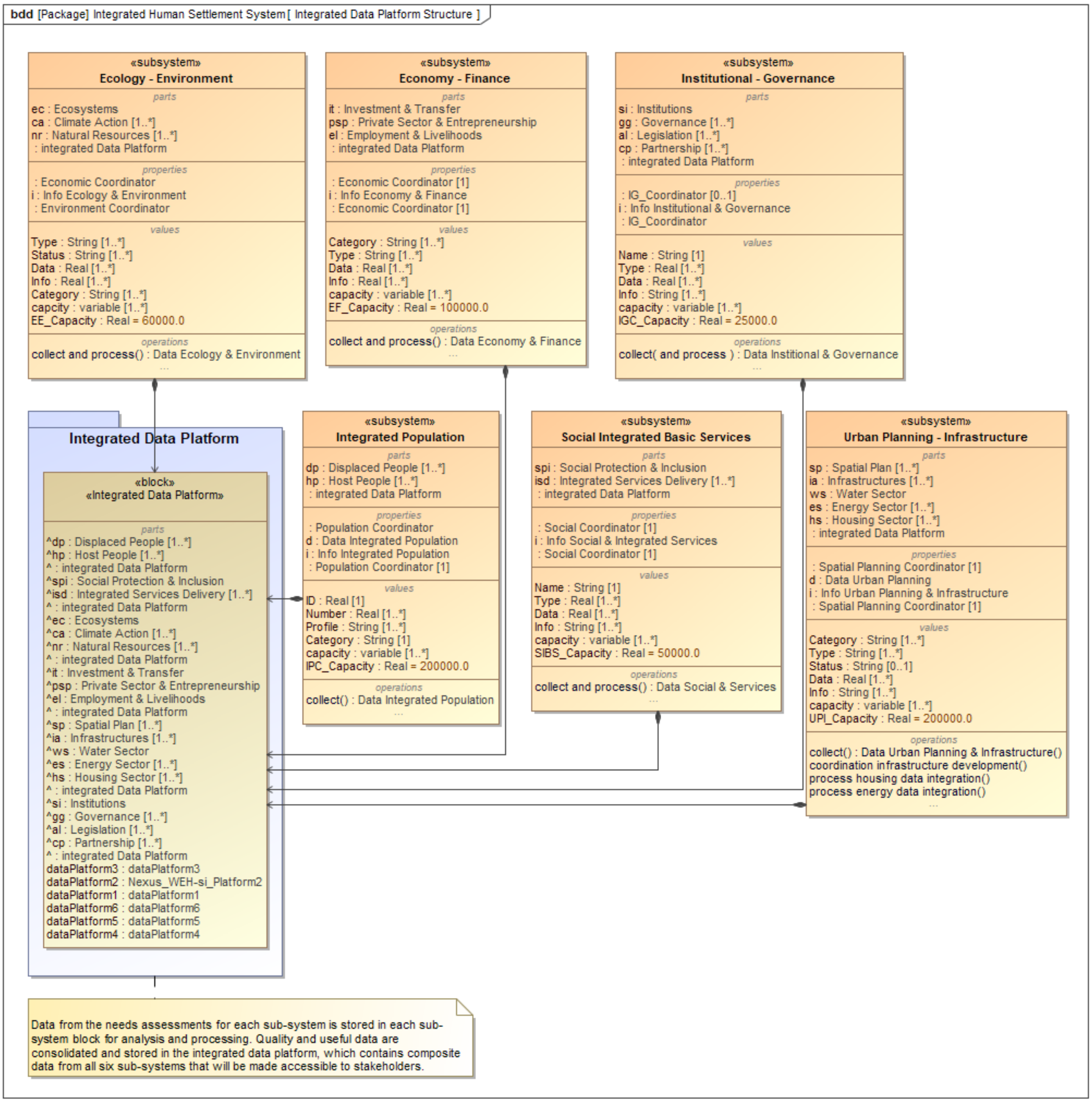

Figure 4. SysML integrated data platform diagram.

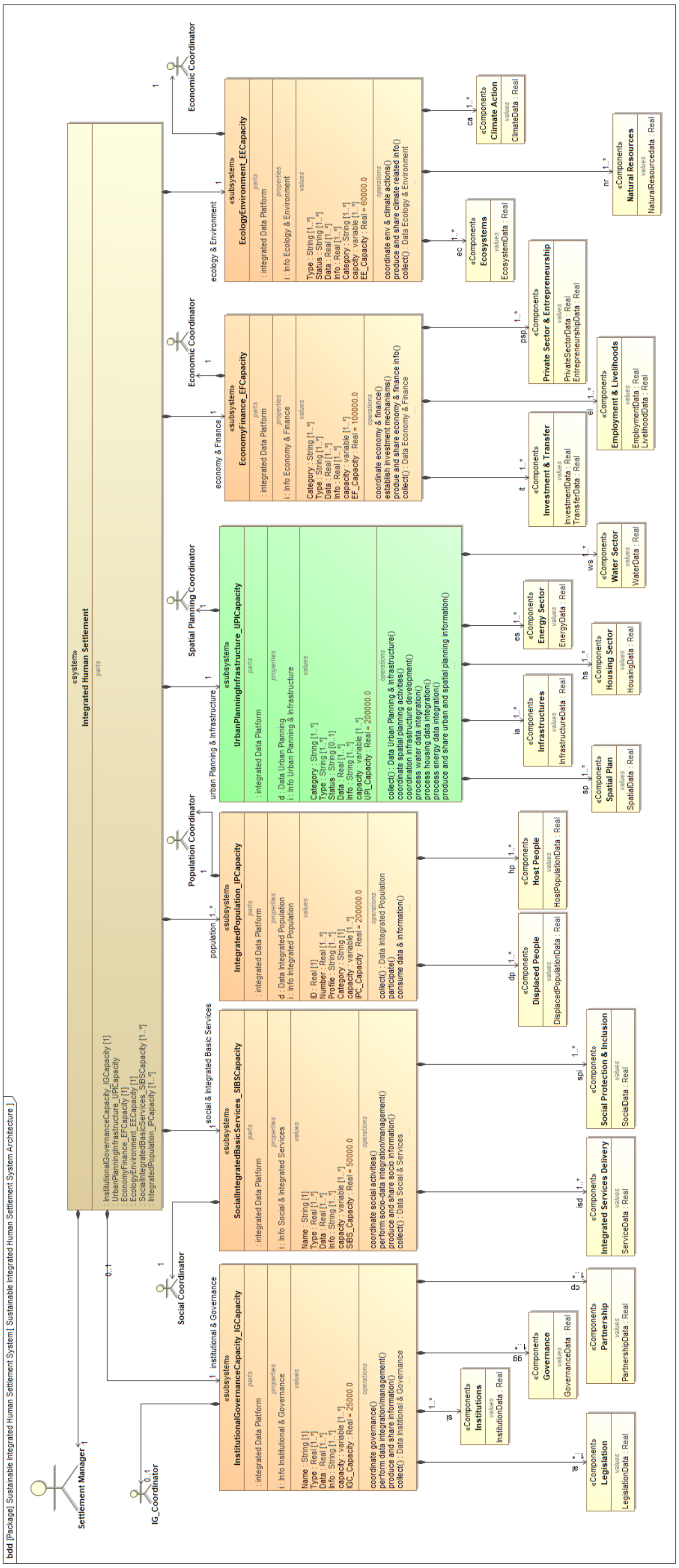

Figure 5. SysML BDD diagram showing the logical architecture of the integrated human settlement system.

assessed. The "Who" and "How" components were much more oriented towards senior executives and government representatives, to gather their perceptions of the relevant decision-making responsibilities concerning the implementation of the model that could be adapted to each given context.

The interviews provided an opportunity to evaluate the proposed model, and led to a consensus that it is a tool that is currently in high demand to better advance the state of change in current approaches, particularly at the United Nations, to the integrated and sustainable development aspects of humanitarian settlements, to better serve displaced people.

5. Conclusion

In concluding this research, it might be useful to note that current literature and approaches to planning and managing humanitarian settlements have failed to provide an integrated system model. It is therefore the added value of this work that has generated a methodology for modeling such a system on a standard platform and provided its visual systemic representation. It presents an integrated human settlement system model that addresses related challenges such as processing and data flow throughput, interoperability, and scalability. This work is of key importance in current debates on the need to reorient humanitarian programs in a more integrated and effective way, in line with the UN's 2030 agenda. It also represents the first attempt to apply systems engineering methodologies to such a complex social domain in a humanitarian context. This work demonstrates that the shortcomings identified in current planning approaches can be effectively resolved using this integrated system model, as it can facilitate a seamless flow of data and information throughout the system. To address the complexities of human settlement in the face of the current systems approach that produces disconnected systems, where subsystems are neither interconnected nor integrated, the proposed modeled systems approach is reactive in that it functions as a system considered as a whole. In addition, the systems engineering approach has been described as a potential means of dealing with operational mega data in complex socio-technical systems while keeping related elements interdependent and well-integrated. The paper explicitly presents the systems engineering approach, MBSE and SysML methodology, described as an interdisciplinary approach to dealing with complex stakeholder problems and complexities.

6. Implications

Taking a quick look at current practices in humanitarian operations and the stakeholders involved, it might seem that the model shouldn't be too academic, as interviewees also revealed. To make it more practical, more understandable, and easier for decision-makers to assimilate, future work would involve integrating MBSE-SysML with other tools, such as MATLAB, or other more "accessible" or "free" applications to perform co-simulation and further analysis and validation. It should be noted that SysML has its limits, and that co-simulation would enable complex dynamic systems to be modeled using other advanced engineering analysis tools. This would certainly lead to 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.

To ensure stable operation of the proposed system model and to enlighten stakeholders on the concept of sustainable integrated human settlement as a complex system of systems, 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 constraining and realistic scenarios, while focusing on the interactions and integration of all subsystems at once, to highlight the added value of integration capabilities that meet system requirements.

Given the shortcomings in the field of operational data processing, this work has enabled the development of an integrated system methodology. Future work would consider other possible perspectives for testing and validating the proposed integrated system model. It would also involve integrating other Sustainable development goals indicators to establish a stronger interdependence and transition between humanitarian aid and development, as was also suggested during the interviews.

Finally, to enable meaningful dissemination of this work to a wider audience, the researcher foresees a series of applications and adaptations in several humanitarian settings, to increase the scope of consensus on its applicability, and ultimately to recommend it as a model and strategic and operational framework complementing other existing guiding principles for settlement planning.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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