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EMPOWER COMMUNITIES: INTEGRATING SCIENTIFIC AND STAKEHOLDER-BASED KNOWLEDGE TO SIMULATE FUTURE URBAN GROWTH SCENARIOS USING ADVANCED TECHNOLOGY FOR BUILT-FORM SIMULATION

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Abstract: This study investigates the possibility of equipping communities with the knowledge, skills, and resources necessary to speed up the implementation of sustainable practices. The goal is to model urbanization by soliciting feedback from different stakeholders within the community. The main objective of this study is to determine how community engagement influences the rate at which sustainability efforts progress in simulation. The research uses a participatory methodology, including stakeholder interviews, meetings, and conversations. The research was conducted in Kurunegala and consisted of three primary phases: framework development, effectiveness testing, and lesson documentation. The framework entailed establishing the computational region, designating predictors, evaluating sub-models, constructing scenarios, and evaluating results. Using CA-Markov cellular automata, agent-based modeling (Net-Logo), the Cellular Automata Python model, and MOLUSCE-QGIS, the study modified the FUTURES model to incorporate stakeholder-based knowledge into urban growth modeling. This study emphasizes the need for bottom-up strategies to achieve long-term sustainability by recognizing the worth of community involvement. When stakeholders in a community are given the opportunity they need to succeed, they are more likely to develop into advocates of transformation and supporters of sustainability initiatives.

Keywords: *Empower Communities, Advanced Technology for Built Form Simulation, Sustainable Development, Technology for Built Form Simulation, Spatial Planning.*

1. Introduction

Many interactions between people and the natural environment, as well as the effects of economic and institutional processes, shape the growth of cities. So, figuring out what's going on at the moment and predicting how cities will grow in the future became very important regarding urban planning contexts. This is because urban growth simulation not only predicts how cities will grow in the future but also looks at the chronology of the problem and how it relates to space and time (Maher Milad Aburas, 2016). Planners use modeling to try to make a realistic model that shows growth trends in the future with a high level of accuracy (Moustaid, 2019). Further simulation models offer a useful analytical way to find safe and effective answers to real-world problems that can be checked quickly, explained to others, and understood easily by everyone (Anylogic, 2021); (Amila Jayasinghe N. R., 2021). During the simulation, a theoretical idea would be changed, so that different choices could be tried out while taking into account the important factors of urban growth. Urban simulation is seen as a way to do research in the field of urban planning based on the factors used and the results of what might happen in the future. (Marengo, 2014). Also, the urban simulation could help figure out what the long-term effects of different policy efforts will be (Janet Davis, 2006).

It is mentioned that most of the new urban simulation models considerably use cellular automata to model urban growth scenarios based on land use and land cover changes. Hassan and Elhassan (2020), Also, most modern models of urban growth tend to focus on modeling the scientific knowledge streams of field experts and pay little or no attention to the stakeholder-based knowledge streams (Hewitt, 2014; Kariuki, 2021). But many researchers pointed out that simply scientific knowledge-based simulation models are limited by different types of knowledge, communication gaps, and a lack of data. This means that they may not be able to make decisions based on the best and most well-tested information (Kariuki, 2021). Integrated models with the participation of stakeholders could help with urban planning because they would take into account how environmental, economic, social, and cultural factors affect each other and how they should be shown in the different ways that the land is used (Robert Newell, 2020) Also, if different stakeholders were involved in the process, it would be easier to deal with complicated decision-making using simulation-based advances (Moustaid, 2019). In the process of simulating different development scenarios (Moira Zellner, 2020), participatory modeling methods could be helpful in capturing changes

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in the context's dynamics. If partners don't take part in simulation processes, the results won't be a true reflection of what will happen (Hewitt, 2014). Because people aren't taking part, the results might not be a good reflection of society as a whole. Also, this would be even more important for growth scenarios in developing countries (Mostapha Harb, 2020; Yang et al., 2019). Participatory spatial modeling and scenario development are ways for researchers to help stakeholders come up with plausible future situations that they can all work on together (Slotterback, 2009). Alexey Voinov (2016) mentioned that increasing the level of involvement requires frequent collaboration with stakeholders and modeling the activities by giving advice on the key indicators and the best ways to measure them. So, this study tries to include stakeholders' points of view in the spatial modeling process while also combining scientific knowledge and stakeholder-based knowledge streams. This is done to make sure that decisions are made based on the best and most reliable information available.

A review of the literature showed that there were some gaps in the research being investigated. In the past, when people made decisions, they often thought about both positive and negative possibilities (Mostafa Harb, 2020). Still, modern technological advances have made it possible to model different layouts and plan the city of the future in the best way (Jesse Penny, 2022). But in simulations, the input of the stakeholder's point of view to making decisions is usually limited (Chingwen Cheng, 2017; Jessica Penny, 2022). So, the first is that we can't model based on the best and most well-validated facts we have. Because modern models of urban growth can't take into account different kinds of knowledge and are limited by a lack of data and a lack of communication (Rebecca W. Kariuki, 2021). This is because these models are only based on land use data and scientific assumptions, not on stakeholder insights. The second problem is that it might not be able to come up with realistic and plausible descriptions while looking at long-term views on urban growth scenarios and dealing with the complexity and uncertainty that come with predicting changes in the environment, society, economy, institutions, and government. Modern models of urban growth are mostly built on data from the past. This means that they might not be able to account for wild cards and some big changes (Moustaid, 2019) and (Janet Davis, 2006). Also, most models that simulate urban growth-based scenarios are based on land use data-driven approaches and scientific assumptions. They don't show social, economic, or political growth triggers, which are also hard to measure (Mathanraj Seevarethnam, 2022), can't use stakeholder-based knowledge streams (Kariuki, 2021), or can't use stakeholder-based knowledge systems (Robert Newell, 2020). The third is that people don't feel like they own the process and don't understand how it works and what it produces (Kariuki, 2021) Because modern models of urban growth are made and used without the help of stakeholders by modeling how experts in the field use modern technology, (Kariuki, 2021). So, the process of modeling and the results it produces are questioned by the people who have a stake in them (Alexey Voinov, 2016). Fourth, few researchers have tried to model urban growth in Sri Lanka (Amila Jayasinghe, 2021). However, none of these studies have tried to include the views of stakeholders or the active input of stakeholders. Still, it is important to include the views of stakeholders in traditional spatial modeling and urban simulation methods.

Urban-SIM, GIS-based modeling, and ENVI-MET are utilized to predict the long-term impacts of transportation and land-use alternatives. Using simulations such as cellular automata and agent-based models, researchers have improved the precision of urban design processes (Majeed Pooyandeh, 2007). Multiple viewpoints can be used to classify these models into categories, such as land-use-based transportation models, complexity-based models (such as CA, agent-based, neural network, and fractal-based modeling), and hybrid models that incorporate GIS and machine learning methods (Ingy El-Darwish, (Elhabib, 2019).

1.1 STUDY AREA

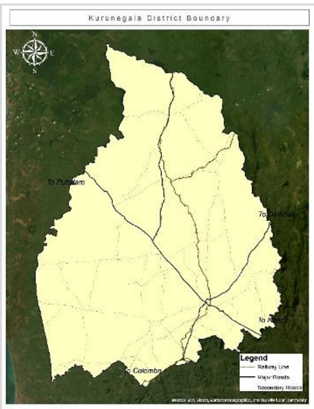


Figure 1, Study area (*Source: Author*)

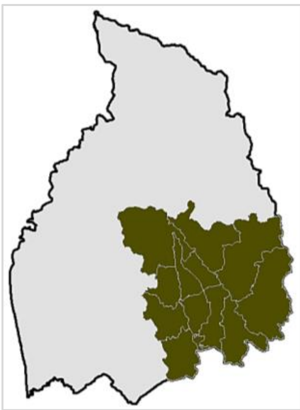


Figure 2, Filtered Study area

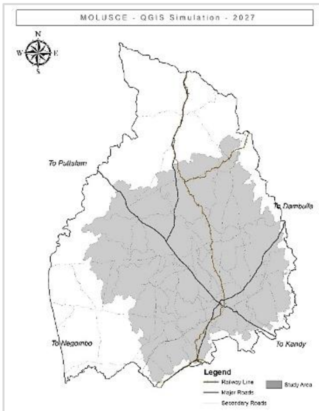


Figure 3, Final Study area

This is the study area chosen for analyzing the simulation of urban development with the participation of key stakeholders which addresses sustainable development. Consequently, this paper is structured as follows. Section 1 provides an overview of the research. The second segment will discuss the methodology of the procedure, while this section will also illustrate the research design. Section 03 consists of the research's findings, and section 04 describes the research's conclusion.

2. Methodology

This study's research method was carefully put together by looking at the relevant literature and best practices in the field. This was done to meet the needs of stakeholders in urban growth models. It shows a deep understanding of how complicated the situation is and gives a solid basis for analysis. Between 2022 and 2027, Cellular Automata (CA) modeling with Python was picked as the first approach. This method makes it possible to show how cities grow and change on a small scale by showing how individual cells interact and change within a certain area. The approach uses CA-Markov chain modeling with IDRISI from 2027 to 2037 for simulating urban sprawl scenarios. By using the probabilistic structure of Markov chains, this integration gives us a better understanding of how cities grow. Agent-based modeling with Net Logo was used to represent the complicated ways that stakeholders act and make decisions. This method, which is used from 2022 to 2037, makes it easier to look into two possible futures. It makes it possible to show how different people, like residents, institutions, or policymakers, interact in an ever-changing atmosphere. Considering the preferences, rules, and relationships of these agents, researchers can get a more nuanced picture of how cities grow. This lets researchers evaluate various policy options and their possible effects. From 2027 to 2037, FUTURES modeling with grass GIS was added to the technique to make the study even better and to exert higher diversity in the results generated. FUTURES, which stands for "Future Urban-Regional Environment Simulation," is a modeling scheme that takes into account several variables, such as land use, transportation, the environment, and social and economic issues. By including all of these different aspects, FUTURES modeling makes it possible to look at the environmental and social effects of urban growth trends as a whole. As a whole, this research consisted of three main phases such as developing the framework, testing, evaluating, and validating the proposed framework, and documenting the lessons learned. In this research approach, considerable emphasis is given to the documentation of the lessons learned while conducting the process.

2.1. RESEARCH DESIGN

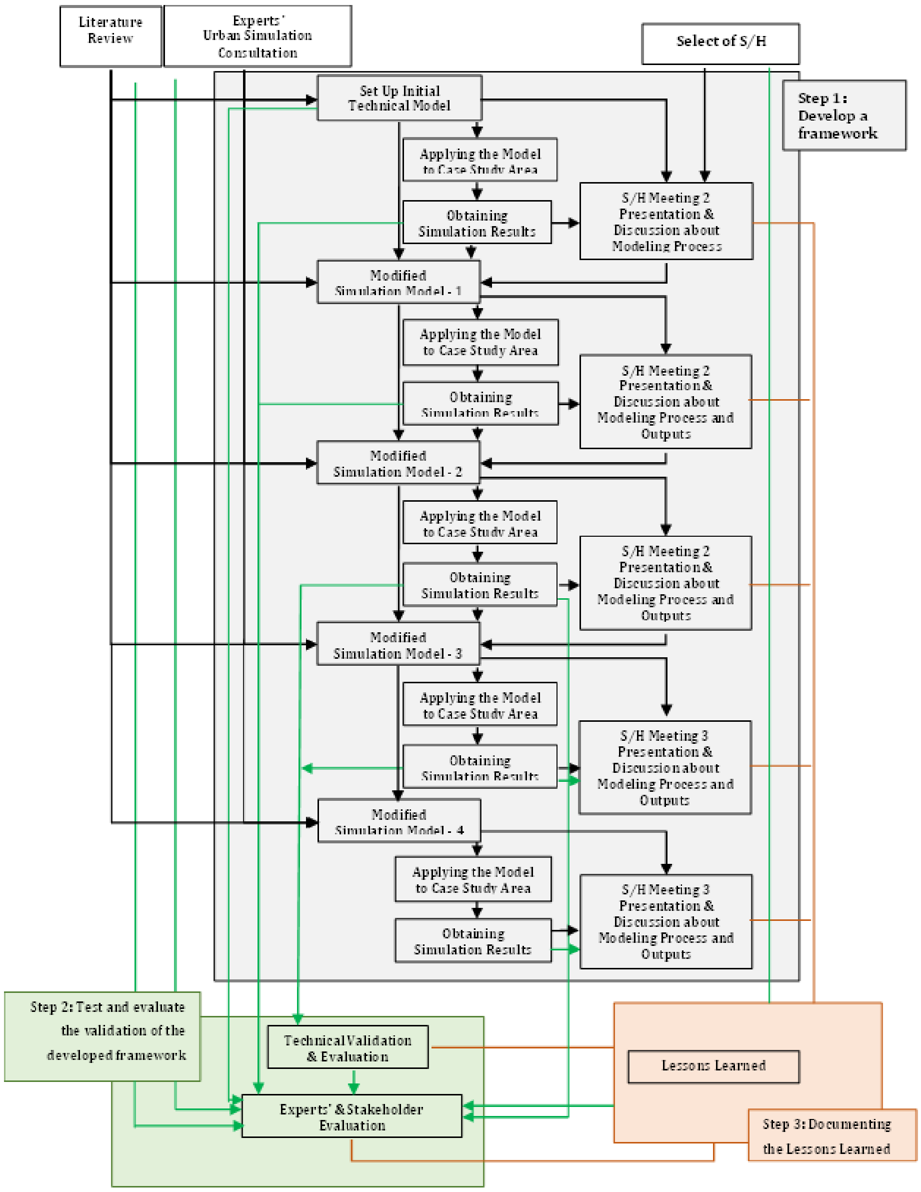


Figure 4, Research Design (*Source: Author*)

The research design is described above and in this approach, it is expected to explicate more on the documentation of the lessons learned during the participatory modeling framework.

3. Findings

We set out the study how the collaborative urban modeling setting contributes to the learning process and how it is relevant to complex urban planning-related problems also, the simulation was done for 5 different scenarios. Therefore, the findings from the overall process of participatory urban modeling have been reported in three separate sections such as, what did the stakeholders learn? What did the researcher learn? And Lessons for improvement. From all the simulations conducted, the ultimate results were evaluated from the ideas of the stakeholders who participated in the overall program and the results are as follows.

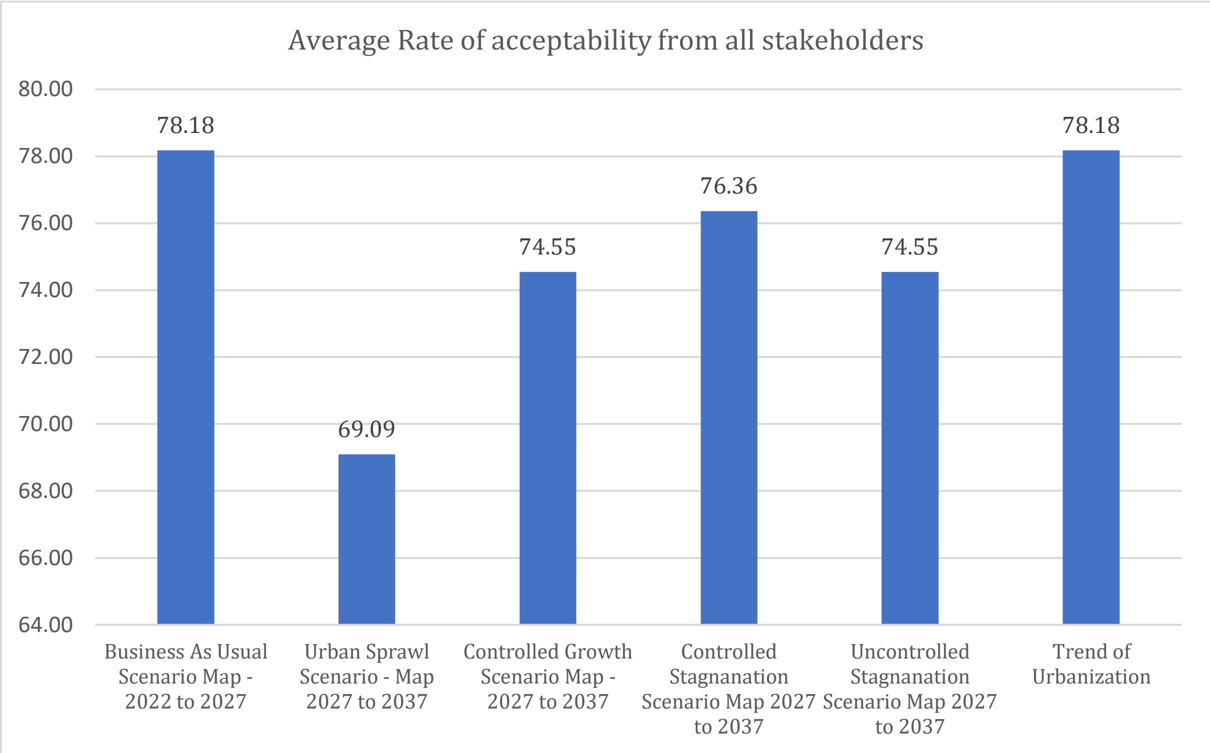


Figure 5, Average Rate of acceptability by stakeholders (*Source: Author*)

The rate of weightings is taken as, highly acceptable – 5, Acceptable – 4, moderately acceptable – 3, Low acceptable – 2, cannot be accepted – 1. These are the weights given for the acceptability of the analysis of the results. Accordingly, the business-as-usual scenario simulation from 2022 to 2027 was accepted by 78.18%. The urban sprawl scenario map was the least accepted one with 69.09%. The other three scenarios and the trend of urbanization result generated from the logistic regression were also accepted by more than 74% of the stakeholders. The likelihood, acceptability, and consistency of the generated results had been evaluated in the above framework and the highest likelihood of occurring in 2037 was assumed to be a controlled stagnation scenario.

3.1. WHAT STAKEHOLDERS LEARNED?

The research project required the selection of a heterogeneous group of 14 stakeholders, including 10 professionals from various disciplines and 4 members of the general public. This heterogeneous composition guaranteed a broad spectrum of knowledge and perspectives regarding growth dynamics in Kurunegala. To improve the understanding and accuracy of the simulated results, Net Logo videos were utilized effectively, producing overwhelmingly favourable comments from stakeholders. It is essential to note, however, that technical obstacles hampered the exchange of experimental aspects employing technological instruments, restricting stakeholder participation to the accumulation of input parameters throughout the very first stages that followed the meetings. During the participatory process, conversations expanded above the boundaries of urban development to incorporate a wide range of diverse themes. The stakeholders' authentic inquiry, motivated by their desires and objectives, prompted the study's researchers to change and create a participative framework following their requirements. It was notable that the stakeholders' active engagement with the presented models, steered the discussions regarding specific and practical alternatives that transcended the domain of broader suggestions. It became apparent that the emergence of "Urban sprawl" was of particular importance to the stakeholders, as it dominated their discussions and directed their investigations. Moreover, the stakeholders have a vested interest in understanding the possibilities and restrictions linked with the anticipated sprawling impact in 2037. This highlighted the need for proactive strategies to successfully oversee and reduce the long-term effects of urban development.

In summary, the research displayed an integrated strategy for stakeholder engagement, incorporating disparate perspectives and knowledge to facilitate significant discussions and informed decision-making. The use of Net Logo videos demonstrated essential in communicating complex concepts and imagined outcomes, while the participatory process enabled stakeholders to actively contribute to practical solutions that tackle the growing issues presented by urban sprawl in the near future.

Table 1 - Six dimensions guided the coding of dialogue content, called "Targets"

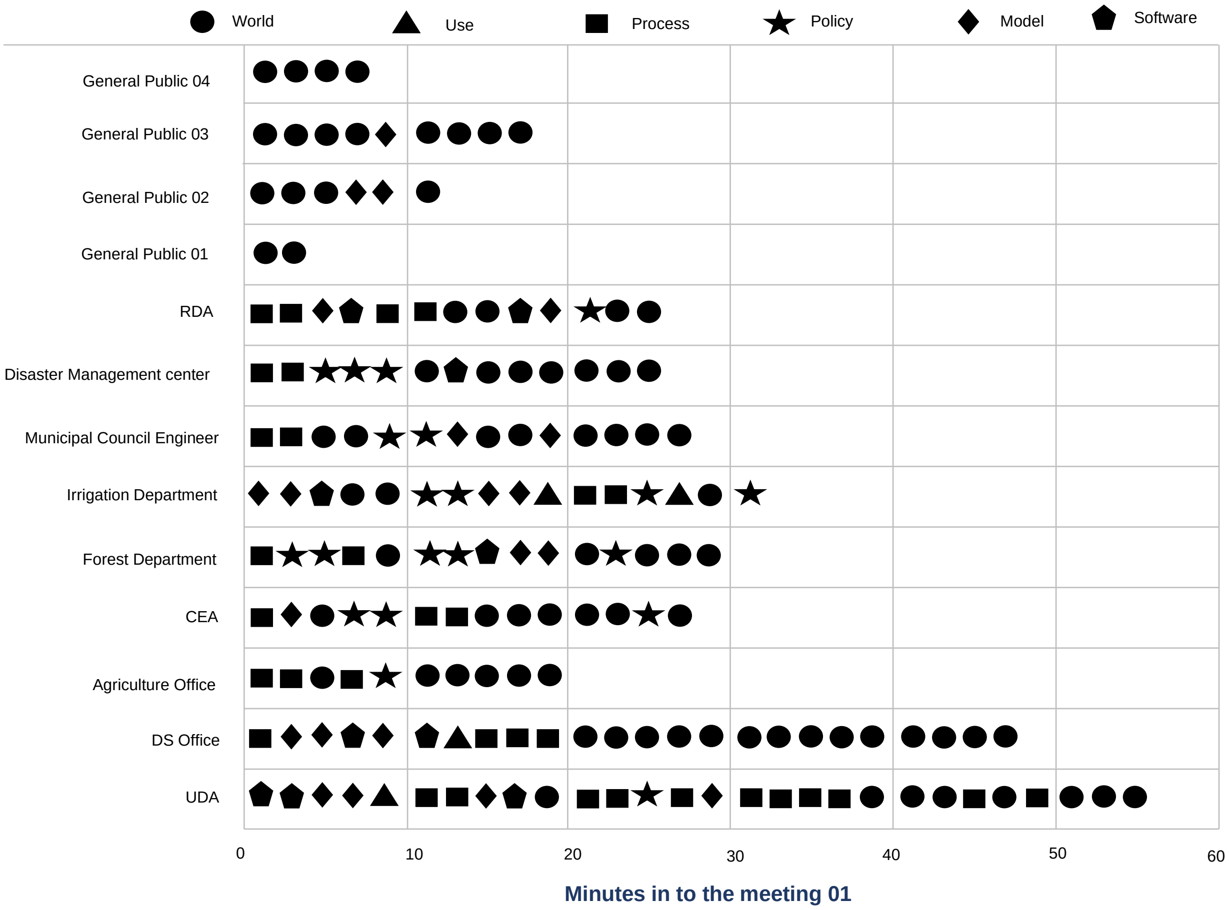
Model	Refers to any component of the models, including Input Variables and Output Variables.
Software	The models are created using computer programs such as FUTURES, CA, CA Markov chain, Net Logo, etc.
World	Referring to biophysical and socioeconomic conditions of the actual world
Policy	About Policies
Use	Referring to how the instruments are employed, their practical utility, or presumptions regarding how they should be employed - Layer preparation
Process	Refers to the norms, structure, facilitation, scenarios, or objectives.

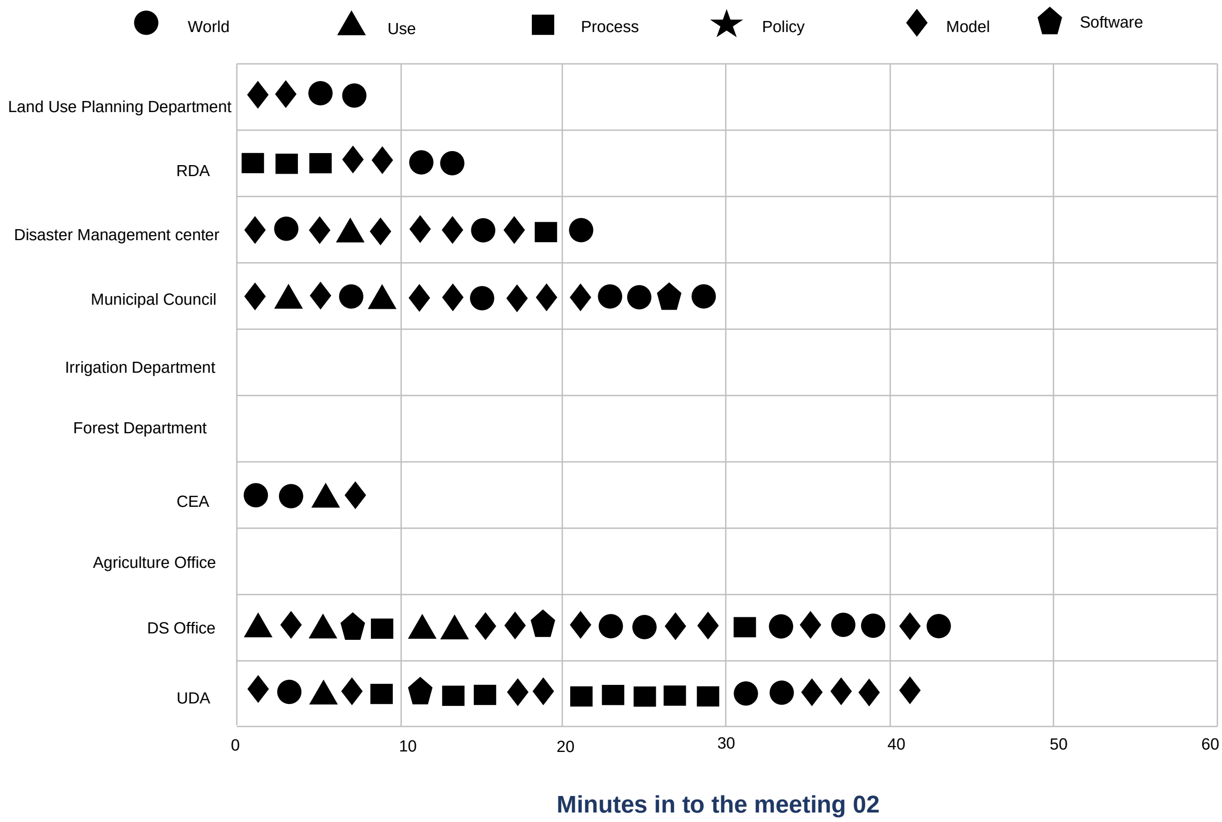
During this procedure, participants did not have complete freedom to independently simulate the development of cities. Rather, they only participated in specific processes and tasks that were part of the overall scheme. At the outset, their primary responsibility was to determine what causes cities to expand. Participants were tasked with identifying and categorizing the most influential factors in the expansion of cities. Once the variables were identified, it became the stakeholders' responsibility to substantiate them. To accomplish this, they had to assign each factor a weight that reflected its perceived significance and influence. This process was intended to establish an order or classification of the factors, which would provide a framework for further analysis and decision-making.

At the second meeting, those with an interest were able to express their desires and viewpoints. During this period, the stakeholders were presented with a variety of growth scenarios for cities. They were asked to consider these possibilities and provide their opinions on the desirability and feasibility of each. Moreover, stakeholders were requested to provide useful comments and suggestions regarding the circumstances. This created an environment where individuals could collaborate to enhance and develop the models. The final meeting concluded the group input procedure. At this juncture, stakeholders were allowed to provide comments regarding the results of the modeling process. This response assessed how satisfied the parties were with the outcomes and the extent to which they met their objectives and expectations. The feedback from the stakeholders was instrumental in determining the accuracy and precision of the modeling efforts. This ensured that the final results accurately reflected the contributions and opinions of all participants. Even though stakeholders weren't provided with full freedom to model the urban development process on their own, the researcher understood it was essential to elucidate the technical aspects. However, because these technological possibilities were so complex and difficult to comprehend, it turned out difficult to get a clear image of them, particularly for certain parties. Nonetheless, the researcher exerted significant effort to provide a general outline and breakdown of the process, bridging the knowledge divide while making it simpler for stakeholders to comprehend the fundamental concepts and objectives.

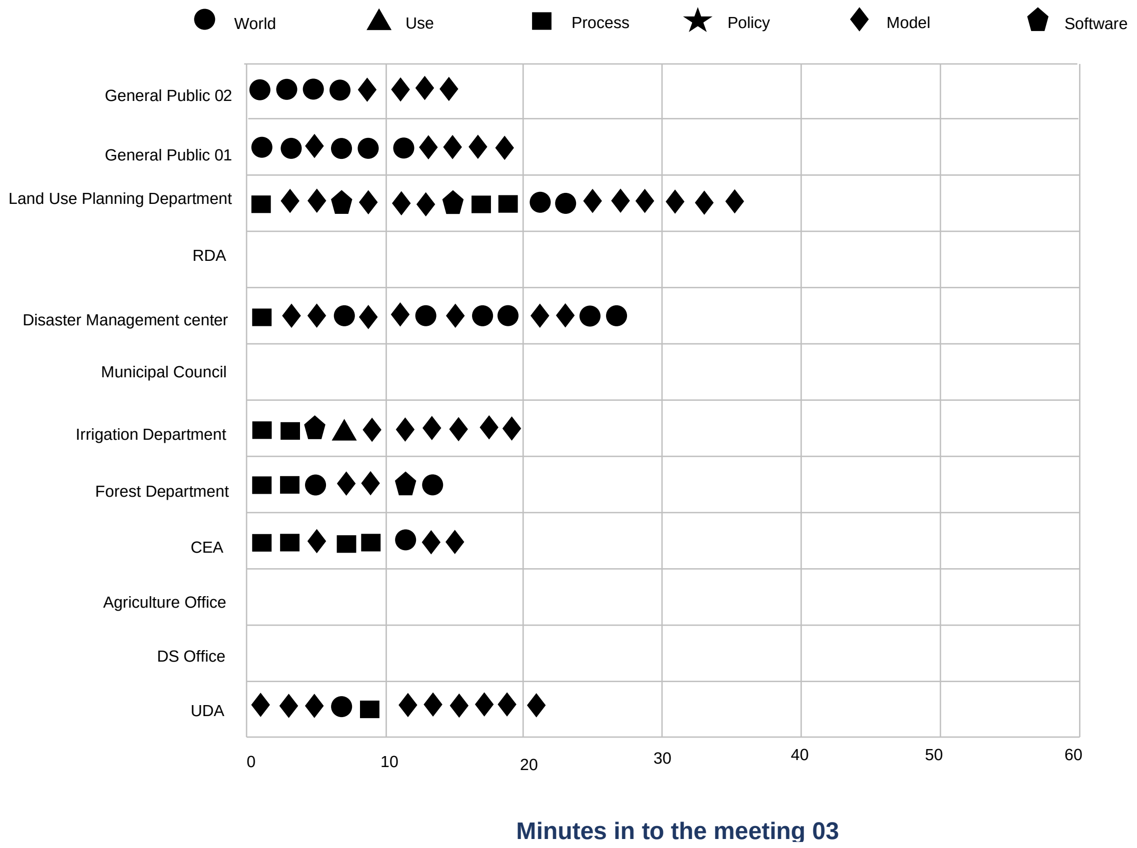
During the initial meeting, the main focus of the discussion concentrated on undertaking an in-depth examination of the various factors that have a significant impact on the urban development distribution within the area of interest. Conversely, there appears to be a comparatively reduced level of interest in investigating the researcher's selected model or in the planned application of the information they had acquired. While a small number of stakeholders exhibited a moderate level of interest in the software tools that would be employed, the majority of attention and examination was focused on acquiring an increased awareness of the complicated interaction and diverse variables that exert an important effect on the complicated processes of urban growth across a broad range of scenarios.

As the second and third meetings approached, a significant number of stakeholders were interested in the urban development modeling procedure. Consequently, it was possible to observe a shift in the focus of participants. During the concluding meeting, results were presented to stakeholders, who provided feedback based on their comprehension of the scenarios and their observations of the visualizations. Thus, the emphasis shifted back to the model outputs. In this approach, the emphasis is placed on six distinct objectives. As the final meeting approached, the duration of the meetings with certain stakeholders was relatively reduced, but the length of the discussions increased. Analytically, collaborative deliberation on the design of future urban development dispersal of Kurunegala inclined more toward the concept of "Collaborative rationality." This suggests observing and conducting interviews alongside the stakeholders on data collection, evaluating the different suggestions, and eventually constructing collaborative conversations among stakeholders which might fundamentally accommodate some individuals with disputes at the onset of the procedure who are probably concerned about its level of complexity (J. Radinsky, 2017).





This method of analysis serves as a framework for determining what transpired during the discussions and how the stakeholders presented their interests during the discourse regarding different objectives. The researcher could substantiate conclusions regarding micro-processes by encoding the conversations (Slotterback, 2009) Participatory modeling would pursue fruitful citizen engagement through participating in a broad range of community conversations. There were restrictions on involving members of the public in this procedure, and as a result, only a handful were coordinated.



3.2. WHAT RESEARCHER LEARNED?

The Learning Sciences technique as stated by J. Radinsky (2017) was used to examine meeting conversations. The selected method comprised recording all sessions in MP3 format, accompanied by a transcription of the conversations and later coding using Moira Zellner's (2020) "targets" methodology, encompassing five aspects linked to the study's topic. Furthermore, the study attempted to record the informal character of discussions by categorizing statements into various "moves," as defined by Zellner (2020), such as OBJ (Objection), OBS (Observation), CLA (Clarification), AGR (Agreement), RFC (Request for Clarification), EXP (Explanation), an RFE (Request for Explanation). Both techniques provide distinct viewpoints on a number of encounters, allowing the researcher to find tendencies that would have been missed via simple observation. The researcher was capable of recording varied degrees of social involvement inside and between interactions by methodically categorizing and analyzing the dialogues, giving empirical information to back up interpretive judgments that go beyond simple observation. This was especially relevant considering the study's emphasis on the way stakeholders are aware of the complicated spatial and temporal relationships connected to urban expansion (J. Radinsky, 2017).

The researcher was able to explore delicate interpersonal communication mechanisms by using this analytical technique that provided insight into how communities collaboratively understand and adjust to changes through time. These studies took into consideration cognitive difficulties that come when individuals lack previous information, experiences, or the capacity to fully prepare. The employment of various coding techniques for each stakeholder enabled the investigation of the variable distribution of acquaintance and adaptation during the discussions or surveys (J. Radinsky, 2017; Moira Zellner, 2020). The researcher recorded complicated elements of interpersonal interaction between and throughout discussions by means of systematic coding and visual representation, producing statistical evidence to support interpretative decisions that exceeded the limitations of simply observing (J. Radinsky, 2017). The coded discussions with every stakeholder are given in the order listed below.

3.3. SEQUENCE OF THE CODING DIALOGUES

Using the graphical interpretations, the conversations were monitored with each stakeholder and consequently, it was able to identify which aspect was highly emphasized by each stakeholder and in which way predominantly on how the graphs were prepared for the interpretations.

In all of the meetings that took place during the 1st round, the primary focus was on the factors that are influencing urban growth, and the majority of participants tended to pose questions and elaborate on the various factors involved. Consequently, once the initial round of meetings concludes, the focus shifts primarily to the model and how it can be utilized. Here are a few examples of how the graphs were prepared for the interpretations shown previously. Here, the sessions of meetings with two constituents were detailed.

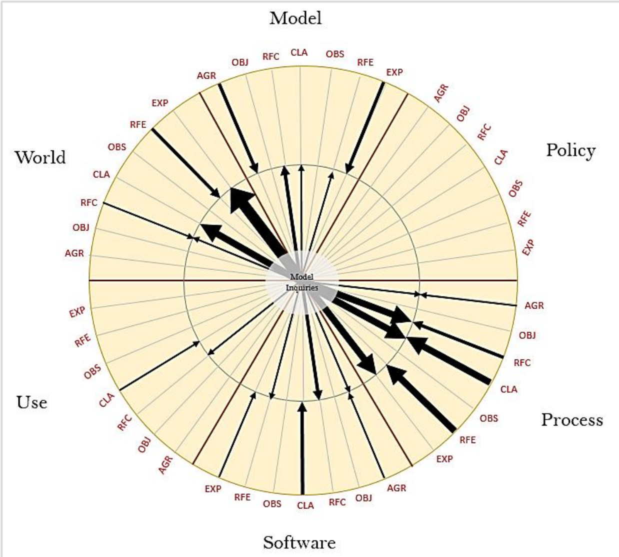


Figure 6, UDA Director NW province – 1st Meeting (*Source: Author*)

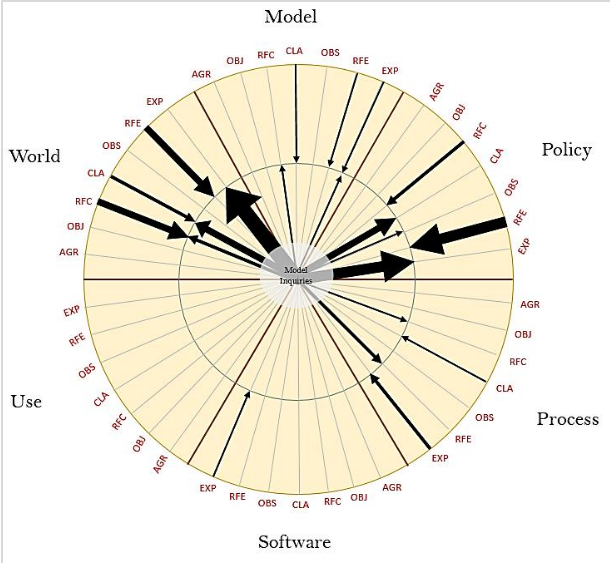


Figure 7, Disaster management Center – Director NW province – 1st Meeting (*Source: Author*)

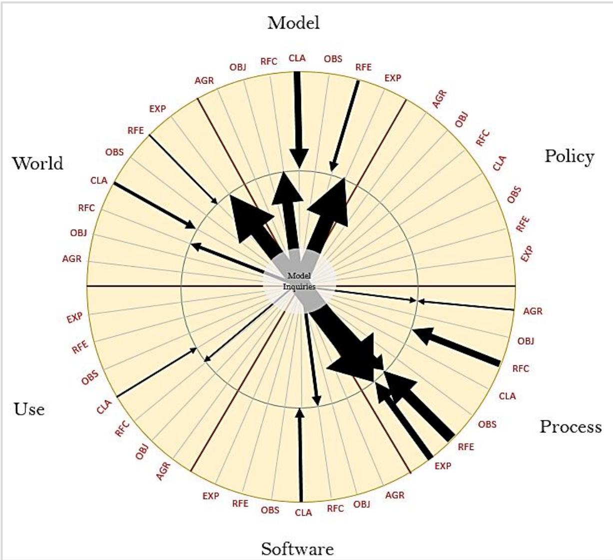


Figure 8, UDA Director NW province – 2nd Meeting (*Source: Author*)

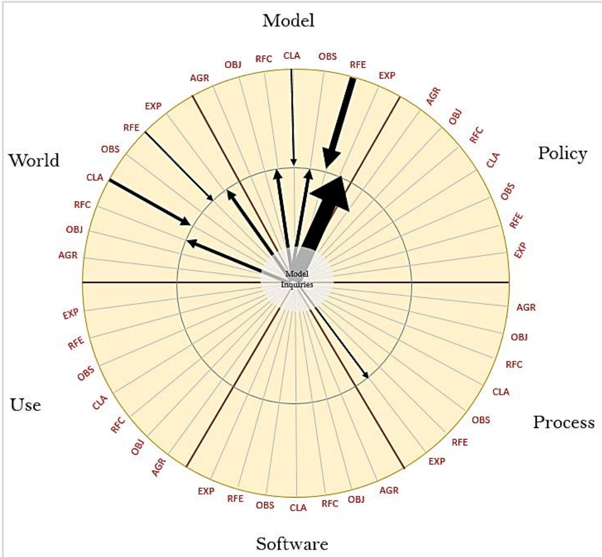


Figure 9, Disaster management Center – Director NW province – 2nd Meeting (*Source: Author*)

As the third meeting drew up to its conclusion, the focus shifted once more to the model outputs. The majority of stakeholders were keenly interested in the model's outputs and the type of development that could be anticipated during the relevant period. Consequently, printed visualizations were used to display the outcomes.

During the third meeting, the major emphasis was on the model's results and the method that had been followed. However, there was a significant lack of focus on the policies involved, technical components of the participatory simulation approach, and stakeholder engagement in the whole process. The meeting focused mostly on the model's outputs and briefly covered the procedural processes followed. Nevertheless, critical aspects such as policy consequences, modeling technical complexities, and identifying the right amount of stakeholder participation were not effectively addressed. The review of the classified dialogue exposes the influence of a number of foundational factors on the conversations. Initially, there was a distinct emphasis on understanding the intricate interactions of the world, processes, and policies surrounding the topic. This emphasizes the significance of obtaining a comprehensive comprehension of the larger context. Secondly, the general population was predominantly interested in the stimulating process of urban expansion. Other variables, regardless of their significance, did not appear to attract their focus to the same degree. This indicates a particular emphasis and inclination in public conversation.

Thirdly, the initial stakeholder meetings displayed a range of involvement concerning the utilization of model tools for simulation. There were significant exceptions among individuals who made an effort to dig deeper into the capabilities and applicability of these tools, even though the majority of stakeholders exhibited a lack of curiosity regarding their complexity. Although interacting with the modeling tools, these interested parties additionally displayed a keen understanding of the regulations regulating urban development in Kurunegala, recognizing their importance in molding the final results. In summary, the initial discussions concentrated on comprehending the complex dynamics of the topic, with special emphasis on the stimulating component that makes up urban development. The level of interest in simulation model tools differed between participants, however, it is noteworthy that particular participants were actively interacting with these instruments while recognizing the crucial role of regulations in shaping urban development processes in Kurunegala. In urban development simulation, it is essential to recognize that future prediction is naturally tough especially when confronting complex systems. As complete reliability is unlikely, the objective is to discover solid approaches that operate well in a variety of possible scenarios (Steven Bankes, 2002). An essential component of urban development evaluation is incorporating stakeholders into the modeling process. By incorporating stakeholders in scenario evaluation and consideration of predictors, their thoughts and viewpoints help develop a more thorough understanding of the issue at hand. This cooperative strategy guarantees that decision-making is not restricted to professionals by itself and instead encourages a participatory environment in which many different groups are actively influencing the future of urban development.

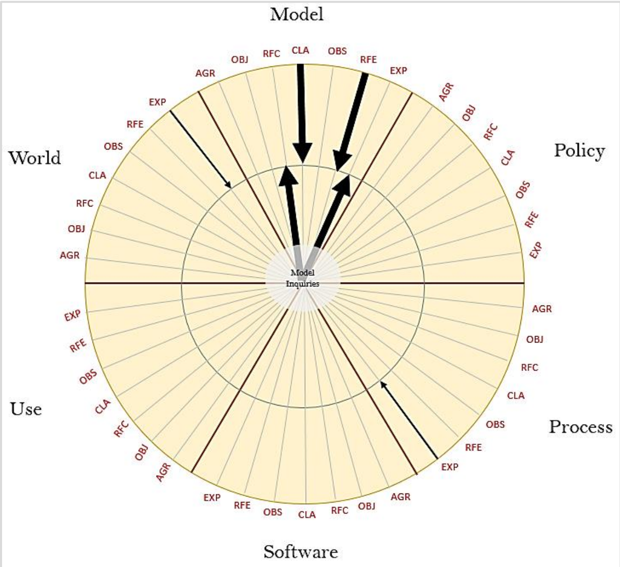


Figure 10, UDA Director NW province – 3rd Meeting (*Source: Author*)

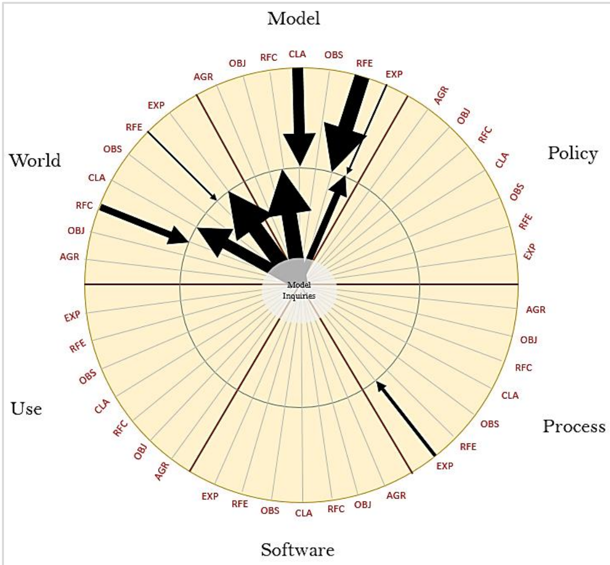


Figure 11, Disaster management Center – Director NW province – 3rd Meeting (*Source: Author*)

3.4. FURTHER FINDINGS FOR THE IMPROVEMENT

Participation of stakeholders in the urban growth modeling procedure demonstrated advantageous in terms of gaining expertise, despite some constraints. It is essential to keep in mind the fact that stakeholders, overall, didn't have knowledge of the technical complexities of the modeling process and exhibited little interest in comprehending the adjustments that contributed to producing outcomes. In addition, performing stakeholder conversations independently, as opposed to in an integrated environment, was time-consuming and difficult. This fragmented strategy impeded the communication of thoughts and a more collaborative environment between stakeholders. In response to the constructive criticism obtained, three additional revisions were made, primarily at the researcher's initiative. Overall, the degree of stakeholder participation in the modeling elements proved to be almost insufficient. To increase the efficacy of stakeholder engagement, it is essential to develop user-friendly modeling tools that are tailored to the technical skills of stakeholders, which includes the general public. By enabling stakeholders to freely participate in the process of modeling, grasp the fundamental processes, as well as independently configure the parameters, a more effective and inclusive strategy can be achieved. Effective integration of stakeholders in participatory simulations requires straightforward interaction, diversified participation, early involvement, capacity development, repeated cycles of feedback, and continued participation. Effective communication makes sure stakeholders understand the objective of the simulation and coordinate their contributions appropriately. Diverse stakeholder participation strengthens conversations and encourages creative approaches. Early participation fosters ownership and permits stakeholders to influence the simulation process. Building capacity enables stakeholders to make an active contribution by enabling them to comprehend the technical aspects. Iterative feedback loops improve trustworthiness and significance. Persistent involvement in the simulation process strengthens the connection between feedback from stakeholders and decision-making, thereby encouraging further engagement.

4. Conclusion

The research demonstrated an approach for simulating urban development scenarios that integrates the latest scientific knowledge and stakeholder input. This structure incorporates stakeholder expertise through multiple phases of conventional urban growth modeling, including describing the computational region, prioritizing urban simulated related factors, examining developmental pressure, reviewing the development suitability, scenario construction, and result assessment, that empowered the communities in decision-making in urban simulation processes. In order to facilitate this incorporation, the research adapted current frameworks and techniques, such as cellular automata, agent-based modeling, and multi-criteria analysis. Validation demonstrated the framework's high precision and efficacy for generating beneficial results. Despite these accomplishments, that were found a few constraints. Due to the study's reliance on just one instance and inability to hold discussions with stakeholders in a single forum, real-time modeling and immediate feedback were hampered. To surmount these constraints, the researchers propose carrying out subsequent case experiments, validating their findings, and implementing subsequent enhancements. Despite this, the suggested structure effectively tackles the constraints discovered by traditional urban simulation frameworks. It integrates scientific presumptions with stakeholder viewpoints to simulate land use modifications, taking into account long-term stakeholder viewpoints and the challenges of predicting environmental, economic, social, organizational, and changes in politics. Collaboration of stakeholders not only improves the reliability of results but also promotes ownership and involvement throughout the process of modeling.

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