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Simulation-Based Participatory Modelling in Urban and Production Logistics: A Review on Advances and Trends

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Abstract: Simulation-based participatory modelling allows integration of all types of knowledge including empirical, technical and scientific from all disciplines and domains. Thus, in recent years, the use of participatory modelling has been continuously increasing in many fields including logistics. With a view of achieving better understanding of the subject, this article systematically reviews the advances made in participatory modelling in the field of urban and production logistics in the last decade. It further reports the findings transparently following a categorization based on (i) the purpose of participatory modelling in the domain, and (ii) depending on the purpose how data is collected, processed and outcomes are presented. The review resulted in 97 articles which were analysed and categorized based on the above two questions formulated in the literature surveyed. The review revealed that apart from the three existing categories of purposes, namely, reflexive, descriptive and normative there is an emerging fourth category that was analytical in nature and 15 out of 97 articles analyzed belonged to this category. The authors decided to call this category analytical field empirical modelling which is primarily based on mathematical modelling and use of computational methods. We present these results with the help of a categorization. During the analysis for the second research question, we discovered that though the conventional ways of data collection and processing, such as interviews and workshops, which remain significantly present, in electronic data crowdsourcing and data processing via computational methods are emerging.

Keywords: participatory modelling; stakeholders participation; urban logistics; production logistics; thematic analysis

1. Introduction

Participatory modelling is defined as a modelling approach in which stakeholders from different domains come together for problem formulation and description, input collection, problem-solving, continuous validation, and finally decision-making [1]. Therefore, stakeholders play a vital role in this process. According to Voinov et al. [1], Basco-Carrera et al. [2], Voinov et al. [3], the focus on stakeholder participation is becoming increasingly important in several fields, and participatory modelling is garnering steady importance as a consequence.

Participatory modelling gained prominence with the collaboration in citizen science when Arnstein [4] proposed the ladder of participation. It was then adopted as a purely qualitative approach to bringing together stakeholders that are involved in the process. In literature [5–8], participatory modelling has been regarded as a qualitative approach that serves a reflexive, descriptive, or normative function. However, as computational methods become more widely adopted, the landscape of participatory modelling is also evolving.

The literature observes a trend in participatory modelling wherein computer-based simulations are a part of the process [9,10] and form the core of the frameworks [2,11]. Simulation-based participatory modelling facilitates the integration of all kinds of knowledge, including empirical, technical and scientific forms, from all disciplines and domains [3]. This allows stakeholders from various backgrounds to be included in the process...
using both qualitative and quantitative methods, and it characterizes the requirements and risks of all stakeholders [12]. This further enables stakeholders from different functional domains with a tool to facilitate discussions as it provides granularity over the simulation model.

With the increasing number of vehicles on roads [13–15], the problems of pollution, congestion, emissions, noise, and road safety are also increasing [16,17]. To address these challenges in a sustainable way, city or urban logistics initiatives are launched to test different new concepts [18,19]. In literature, urban and city logistics are used interchangeably [20]. In this article, we use the term urban logistics where we mean urban or city logistics to keep the exposition simple. Similarly, goals of production logistics can be formulated as pursuance of better delivery and reliability with the minimum possible logistic cost [21].

Myopic decisions based on inaccessible or incomplete information can trigger severe harm even if not intended; thus, indicating the importance of a holistic perspective [22]. Given the inherent limited knowledge of domains, it is important to include diverse opinions on a subject matter [23]. Since both urban and production logistics include multiple stakeholders, participatory modelling is increasing being used to solve problems in the domain.

More companies and cities are adopting participatory modelling to manage the flow of goods and passengers; hence, resulting in more existing studies in the area. In their work on urban logistics, Mangano et al. [24] and Zenezini et al. [25] proposed models using participatory methods to explore the dynamics of diffusion between logistics service providers and municipalities. In addition, Le Pira et al. [26] and Marcucci et al. [27] in their recent work proposed a methodology to address the complex problem of multiple-stakeholder decision-making in urban freight logistics. System Dynamics (SD) was adopted in Mangano et al. [24] and Le Pira et al. [26]. Katsela and Pålsson [18] and Marcucci et al. [27] employed agent-based modelling (ABM) and the discrete choice method (DCM) while proposing the respective models. Recently, Singh et al. [11] proposed a framework for the involvement of stakeholders in logistics, demonstrating a growing interest for participatory modelling in urban and production logistics.

To the best of our knowledge, no review has been conducted in the field of urban and production logistics that employs simulation-based participatory modelling. Therefore, in this article, we intend to understand the different trends in simulation-based participatory modelling in the logistics domain wherein stakeholders from urban areas and companies are also involved in the decision-making processes discussed above. We achieve this via a systematic literature review that categorises the direction of participatory modelling in the last decade according to the purpose it serves.

With this view in mind, we perform a review of participatory modelling in the domain of production and urban logistics. Since 2017, we see a rise in the number of articles that employ participatory modelling using simulation-based techniques. These articles in their research work take multiple perspectives ranging from policy-making to traffic and logistics management. These articles employ participatory modelling using simulation tools while proposing models that help solve collective decision-making but no study to the best of our knowledge focusses on the methodology and advances in simulation-based participatory modelling itself. Therefore, we believe that it is apt to do a systematic review that focusses on it.

To evaluate the advancements in participatory modelling within the domain of logistics with simulation, this study considers two refined research questions:

- With the use of computers, how is the landscape of the purpose of simulation-based participatory modelling changing?
- With the changing landscape, what are the methods and techniques used in different phases of participatory modelling?

The first question investigates the purpose of participatory modelling and characterizes the application of computers in the limiting scope of participatory modelling in urban
and production logistics in the last decade. This is achieved with the help of a systematic literature review, which analyses the literature for trends or any significant direction it takes in the domain.

Reflecting on the needs of simulation-based participatory modelling with the changing trends in literature, the second question studies the changes in the tools and methods used for participatory modelling, following the increase in the use of computers in the domain. This is further analyzed with the help of categorization during the different phases of participatory modelling which, underlines the technological changes in the field. In addition, this question is also interpreted in the limited domains of production and urban logistics.

The remainder of this article is structured as follows. In Section 2, we discuss the research methodology which first filters the articles to be studied and then explains the descriptive and thematic analyses of the articles. The first research question is analyzed through and is further classification into the categories according to the purpose participatory modelling serves in the selected articles. The second research question is analysed wherein the different phases for participatory modelling are described. In the next section, results are synthesized and presented in a categorization proposed, followed by the direction of future research. Lastly, we present the Conclusion together with limitations and implications of the work.

2. Methodology

In this Section, we transparently illustrate the findings by rigorously synthesizing prior research, which guarantees the reliability and replicability of the study. This section first underlines the procedure through which data was collected and analysed, in accordance with the steps enumerated by Säfsten and Gustavsson [28]. This work by Säfsten and Gustavsson [28] outlines a methodological approach for systematic literature reviews in the engineering field. The following steps were taken comprehensively to complete the review:

Specify the purpose of the literature review. Firstly, a purpose and possible research questions are formulated where the idea behind carrying out the review is concretely stated. This forms the basis and facilitate the planning of the literature review.

We, in this first step, defined the scope of our literature review which is to study the evolving nature of participatory modelling in the domain of production and urban logistics with the increase in the computational power available.

Identify suitable keywords. In this step, keywords for database searches were to be identified. This depends on the research questions formulated in the first step. However, a point of departure may be the keywords for theoretical concepts. Also, different synonyms for the keywords should be included in the searches. As the relevant literature is identified, more keywords may be included from the new knowledge obtained.

Because the study primarily considers the domains of production and urban logistics, they are considered as the first group of keywords. Together with the aforementioned keywords, logical operators are used to cover the scope of this article.

Search string: ((participatory OR collaborative) AND (model* OR design)) AND (computer-based OR simulation) AND (logistics OR production AND logistics) OR (urban AND mobilit* OR development) OR (urban OR infrastructure AND plan*)

A search was conducted with the combination of the abovementioned keywords in their title, abstract, or keywords. Asterisk (*) was adopted to expand the search in the said areas.

Formulate criteria for including and excluding literature. Next we decide the basis of including literature in the review. This may be the type of publication, period of time, and language in which articles are written. It may be a good idea to be open to include different types of literature and as more knowledge is acquired exclusion criteria can be formulated. As shown in Figure 1, based on the scope of the literature review, we formulated the inclusion and exclusion criteria for articles that were required to answer the research questions.
We started with the inclusion criteria as explained in Table 1. As we obtained knowledge in the area, we iteratively formulated the exclusion criteria for the literature review. We understood the definition and scope of collaborative logistics and decided to exclude it from the review after the first round. For complete inclusion and exclusion criteria adopted in this review, please refer to Table 1.

Table 1. Criteria for inclusion and exclusion of articles.

| Type       | Criteria                                                                 | Rationale                                                                                                                                 |
|------------|--------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Inclusion  | Title, abstract and keywords must demonstrate any possible implementation of participatory modelling in production and/or urban logistics. | To include all potentially relevant studies, the search was not limited to specific journals. Research from other subjects may also appear in the search. In the subsequent steps, it was ensured that articles with a clear focus on participatory modelling in the domain of production and urban logistics are included in this review. |
|            | Articles must be published in peer-reviewed journals or conference proceedings. | To ensure quality control, only peer reviewed journal articles and conference proceedings were included in the review [29].                |
|            | Articles published between Jan 2010–Jun 2021 were considered for the review. | This criteria was deduced from the objective of the article which is understanding the recent trends and advances in the domain. From the different article databases, we found out that English is the dominant language in production and urban logistics domain. |
|            | Articles must be written in English.                                      |                                                                                                                                          |
| Exclusion  | Articles focussing on collaborative logistics were excluded.              | Since the definition of collaborative logistics [30] indicates another area of study than participatory modelling, it was excluded in the review. The review focusses on participatory modelling in production and urban logistics; therefore, studies from other contexts were excluded as per the definition in the work by Singh et al. [11]. |
|            | Articles not focussing on participatory modelling.                        |                                                                                                                                          |

Select search tools and databases. This is a crucial step in the literature review and should be done in consultation with senior researchers and university library as they have updated information and are very knowledgeable.

The databases selected for the systematic search were Scopus, Web of Science, IEEE Access, and Google Scholar. According to Reda et al. [31] and Tornese et al. [32], Scopus and Web of Science were used to make a complete literature review in the field of logistics engineering and science. Further, IEEE and Google Scholar were used to mitigate any bias in the study due to the chosen databases. Thus, a vast range of article were searched and filtered which cover the entirety of academic and industrial research.

Formulate a search strategy and perform searches. There are various search strategies, for example, string search and snowballing. String search is an approach where literature search is performed using identified keywords and their synonyms. In snowballing, there are two approaches (i) backward and (ii) forward. In backward snowballing, we scan the articles cited in the initially selected articles whereas in forward snowballing we identify the articles citing the initially selected articles [33,34].

Based on the search criteria, 376 articles were filtered and data corresponding to these articles were collected based on the review by the team. In total, 160 articles were filtered from Scopus whereas 192 scientific documents were retrieved from Web of Science, IEEE,
and Google Scholar. Eight articles were in the purview of existing knowledge, which resulted in 29 articles via snowballing.

**Summary review of identified literature.** The results of the searches are evaluated throughout the process to check whether the results conform to the expectations. In this step, identified keywords or inclusion and exclusion criteria may need to be adjusted. A first round of elimination of articles is often based on the results of reading title, keywords and abstracts.

In this step during our systematic literature review, we adjusted our keywords from the knowledge obtained by reading the title, abstract and keywords of initially selected articles. We also iteratively refined our inclusion and exclusion criteria in this step as explained in Table 1.

**In-depth review of identified literature.** The review is carried out in more depth once the literature meeting the set criteria is identified. In this step, the identified literature is read in its entirety and literature may be excluded at the step if the set criteria is not met upon reading a complete article. At this point also, grey literature is excluded as mentioned in Table 1 and Figure 1.

![Figure 1. Step-by-step procedure of the systematic literature review.](image)

During the course of our literature review, 376 articles were initially identified through databases, eight from existing knowledge, and 29 articles through snowballing. Out of these, 47 duplicate or common articles were removed from the article repository. We read and analyzed title, abstract and keywords of 366 articles which resulted in 122 articles. Full content analysis was done for these articles and further grey literature was removed upon among the authors.

**Extract data and create summaries.** For each article selected, relevant data need to be extracted in a suitable manner. These summaries can be created and maintained using various tools varying from sophisticated softwares to simple spreadsheets.

We created and maintained a spreadsheet wherein we collected data based on the set criteria. This spreadsheet was further color-coded depending upon the inclusion (green),
exclusion (red) and maybe categories (yellow). We used fairly standard color coding. The articles falling into maybe categories were further discussed and a decision was made by the authors to either include or exclude the article.

**Analyze contents.** There are different techniques for analyzing the results of a systematic literature review. In case of a comprehensive literature review, both descriptive and thematic analyses are done. In descriptive analysis, an overview and description of the selected articles were considered and in thematic analysis content is analyzed based on the purpose and research questions of the literature review.

In this article, descriptive and thematic analyses form a major part of the study and was performed in detail. Below we first discuss the descriptive analysis in which we present an overview and description of the selected literature.

2.1. Descriptive Analysis

The general trend of articles published in the participatory modelling in production and urban logistics field indicate an increase in the number of articles. Particularly, in 2019, there was a surge in the number of articles in this area, as illustrated in Figures 2 and 3.

![Figure 2. Categorization of articles based on the year of publication.](image)

![Figure 3. Categorization of articles based on the purpose they serve in participatory modelling.](image)

The search was concluded in June 2021, showing a significant decrease in the number of articles in 2020 does not, as there are not as many articles as in the previous year. This could be attributed to the global pandemic, which disrupted meetings and other forms of data collection, although the researchers have only little evidence to support this claim. The three major journals for publishing these articles were: sustainability, Environmental Modelling and Software, and Land Use Policy. In addition, 97 scientific
documents out of 366 were filtered based on the title, keywords, and abstract. Here, literature not focusing on participatory modelling was excluded. For example, our search string had both collaborative and participatory modelling; however, collaborative logistic could mean a specific technical term in supply chain literature. Such documents were excluded from the list, thereby resulting in 97 scientific documents.

Another trend that the research team noticed was that engineering departments have increasingly started adopting participatory modelling with the rise in computational methods and empirical modelling as compared to the past research wherein researchers mostly came from the domains of management and human sciences.

The articles not included are review articles that were not pertinent to the field of logistics, collaborative modelling, and control systems, including articles focusing on future technologies in the fields of collaborative modelling and reverse logistics. Articles related to flood risk and the framework for its control were also not included in the analysis, as these articles are far from the production and urban logistics domain.

2.2. Thematic Analysis

Next, we perform thematic analysis by reviewing content of the selected literature based on the scope and research questions for the systematic literature review. We perform and present the thematic analysis based on our research questions: with the increase in computational power available (i) how is the landscape of the purpose of simulation-based participatory modelling changing; and (ii) how the methods and techniques used therein are evolving.

2.2.1. Purpose of Participatory Modelling

This section filters articles according to the purpose simulation-based participatory modelling serves in the article. Three major categories viz, communication, decision-making, and knowledge generation, have been discussed in the existing literature which is being reasserted in our literature review. However, we see an emerging field of empirical modelling in the domain that occurs due to the use of computational methods. We discuss it under the subsection emerging field.

Communication

Participatory modelling serves as a platform for cross-functional domains and thus facilitates a dialogue among stakeholders. This category in literature has been described as reflexive and instrumental in the process of participatory modelling. In the systematic literature review, we inferred that the communication could be further classified into two categories depending on the purpose it serves: conflict resolution and stakeholder engagement.

During our literature review, we deduced that 28 articles were focussing on communication in the two above mentioned forms in which three articles [35–37] focussed entirely on conflict resolution and other articles focussed on stakeholder engagement.

Voinov et al. [3], Mangano et al. [24], Grogan [35], Nae et al. [36], Karimi and Brown [37], Yang et al. [38], Kumar et al. [39], Kuru and Ansell [40], Leonard et al. [41], Stave et al. [42], Artopoulos and Costa [43], Pardo-García et al. [44], Andreani et al. [45], Rall et al. [46], Olazabal et al. [47], Rexhepi et al. [48], Fiandrino et al. [49], Sharifi et al. [50], Le Pira et al. [51], Olszewski et al. [52], Neuenschwander et al. [53], Shaqat et al. [54], Stauskis [55], Forlano and Mathew [56], Lewis et al. [57], Rosol [58].

Decision-Making

In our review, the second category of which we reasserted its existence the decision-making or the normative category wherein the actions were decided and recommendations were made accordingly. This category could be classified as having the outcome of the simulation-based participatory modelling as policy recommendations and planning results.

There were in total 31 articles that fall in this category and were used explicitly in decision-making based on policy or actions recommendations. During our analysis we...
saw that out of these articles, two articles [59,60] focus on policy recommendations as their results; whereas all other articles focus on planning actions. Hence, we divided this category further into outcomes as policy recommendations or planning results.

Malekpour et al. [8], Marcucci et al. [27], Neuenschwander et al. [53], Halligey [59], Pereverza et al. [60], González-Méndez et al. [61], Melkonyan et al. [62], He et al. [63], Firman-syah et al. [64], Indrajit et al. [65], Gashu and Gebre-Egziabher [66], Omidipoor et al. [67], Stańczuk-Gałwiaczek et al. [68], Fuldauer et al. [69], Sahin et al. [70], McEvoy et al. [71], Macmillan and Woodcock [72], Moore and Elliott [73], Krzywoszynska et al. [74], Ducrot et al. [75], Long et al. [76], Randhir and Raposa [77], Graveline et al. [78], Brits et al. [79], Vermote et al. [80], Brand [81], Khan et al. [82], Muste et al. [83], Dearden and Wilson [84], Gaddis and Voinov [85].

Knowledge Integration

The third purpose that has been described in the existing literature is the descriptive nature of participatory modelling. This refers to the purpose of knowledge integration, which can also be further classified into vertical and horizontal integrations [86]. Integration, either horizontal or vertical, depends on whether the stakeholders are on different levels in the same domain and hence they are integrated vertically or, it brings together stakeholders from different domains and integrates the knowledge produced horizontally.

A total of 23 articles focus on knowledge generation, in which four articles [87–90] explicitly discuss vertical integration [88] and the remaining implicitly involve horizontal integration, as they bring together stakeholders from different domains. Therefore, we can infer that participatory modelling in the past has mostly been used in bringing stakeholders from different domains to the table.

Voinov et al. [1], Artopoulos and Costa [43], Pascariu and Pascariu [87], Smajgl [88], Hedelin et al. [89], Pfeffer et al. [90], Kariuki et al. [91], Strith et al. [92], Fu et al. [93], Dierich et al. [94], Weimann et al. [95], Elliot et al. [96], Smetschka and Gaube [97], Venturini et al. [98], Drogoul [99], Endo et al. [100], McDermott et al. [101], Archetti et al. [102], Leskens et al. [103], Hewitt et al. [104], Beirão et al. [105], Winkler et al. [106].

Emerging Field–Empirical Modelling

During our critical analysis of the systematic literature review of the last decade starting from 2010 to June 2021, we observed an emerging field, which employed computational methods as the primary purpose of the participatory modelling, thus yielding quantitative results for the stakeholders to base their discussions on. We call this field empirical modelling that is based on the analytical nature of the simulation-based participatory modelling.

We define empirical modelling as the modelling that is based on mathematical abstractions of the real-life scenarios, and thus the simulations and optimizations produce quantitative results that form the core of discussions in participatory modelling. We see a spike in the trend towards the end of the decade, which could also be seen as the trend inline with the availability of high computational power.

We found 15 articles out of the total 97 articles to be in the field of empirical modelling, which we could not attribute to any of the other three categories. Further, we observed two major trends of purposes within the analytical nature as numerical results and validation.

Grogan [35], Elliot et al. [96], Middya et al. [107], Li et al. [108], Thondoo et al. [109], Quan et al. [110], Vieira et al. [111], Adamek et al. [112], Silva and Novaes [113], Montalto et al. [114], Anand et al. [115], Campbell and Im [116], McGarity et al. [117], Ranjan [118].

2.2.2. Methods Adopted in Participatory Modelling

According to Voinov et al. [3], the process of participatory modelling can be divided into three major categories, namely, input collection, data processing and output presentation. In this section, we briefly describe how the input collection, data processing, and output presentation are done while adopting simulation-based participatory modelling in the domain of production and urban logistics. Accordingly, we attempt to correlate the
three phases and the trend of how they are evolving with the increase in computers in the domain.

On one hand, we observe that some conventional qualitative methods still have a prominent presence in the simulation-based participatory modelling; on the other hand, there are new computational methods being employed in the field. We perform a critical analysis of how these trends appear in the three phases of participatory modelling in the production and urban logistics domain.

**Input Collection**

We describe input collection as the process of data collection that serves as input for the simulation-based participatory modelling and takes strict precedence over data processing data in chronological order. In the conducted review, this phase varies from crowdsourcing the data to using existing databases for input data collection. We enumerate the different kinds of tools and methods for input collection, together with the articles that employ them, in Table 2.

**Table 2. Analysis of tools and methods used during different phases simulation-based participatory modelling**

| Phase                  | Method                           | Tool                     | Reference                                                                 |
|------------------------|----------------------------------|--------------------------|---------------------------------------------------------------------------|
| Input collection        | Crowdsourcing                     | PPGIS                    | Voinov et al. [1], Nae et al. [36], Karimi and Brown [37], Rall et al. [46], Indrajit et al. [65], Pfeffer et al. [90], Endo et al. [100] |
|                        |                                  |                          | Kuru and Ansell [40]                                                     |
|                        |                                  |                          | Karimi and Brown [37], Stave et al. [42], Rall et al. [46], Stauskis [55], Stańczuk-Gałwiaczek et al. [68], Smajgl [88], Pfeffer et al. [90], Thondoo et al. [109] |
| Field notes & surveys  |                                  |                          |                                                                          |
| Interviews             | In-depth interviews, semi-structured interviews, etc. |                          | Voinov et al. [1], Marcucci et al. [27], Nae et al. [36], Yang et al. [38], Kumar et al. [39], Stave et al. [42], Olazabal et al. [47], Sharifi et al. [50], Shafqat et al. [54], Stauskis [55], Rosol [58], Halligey [59], He et al. [63], Firmsmasyah et al. [64], Omidipoor et al. [67], Stańczuk-Gałwiaczek et al. [68], Fuldauer et al. [69], Macmillan and Woodcock [72], Krzywoszynska et al. [74], Ducrot et al. [75], Long et al. [76], Vermote et al. [80], Brand [81], Smajgl [88], Hedelin et al. [89], Pfeffer et al. [90], Dierich et al. [94], Smetschka and Gaube [97], Droogou [99], Endo et al. [100], Leskens et al. [103], Thondoo et al. [109], Vieira et al. [111], Campbell and Im [116] |
| Workshops              | Single level workshops, multi-level workshops, etc. |                          | Olazabal et al. [47], Rexhepi et al. [48], Olszewski et al. [52], González-Mendoza et al. [61], Melkonyan et al. [62], Macmillan and Woodcock [72], Krzywoszynska et al. [74], Graveline et al. [78], Brits et al. [79], Smajgl [88], Hedelin et al. [89], Kariuki et al. [91], Dierich et al. [94], Weimann et al. [95], Hewitt et al. [104] |
| Roleplaying            |                                  |                          | Le Pira et al. [51], Fu et al. [93]                                       |
| Questionnaires         |                                  |                          |                                                                            |
| Focus groups           | Focus interviews, etc.            |                          | Voinov et al. [1], Mangano et al. [24], Rosol [58], Ducrot et al. [75], Smajgl [88], Endo et al. [103] |
| Input data             | Spatial data/GIS                  |                          | Nae et al. [36], Fiandrino et al. [49], NeuenSchwander et al. [53], Lewis et al. [57], Omidipoor et al. [67], Vermote et al. [80], Khan et al. [82], Hedelin et al. [89], Strith et al. [92], Dierich et al. [94], Beirão et al. [105], Dembski et al. [120], Gaudron et al. [121], Groegan [35], Nae et al. [38], Yang et al. [38], Leonard et al. [41], Fiandrino et al. [49], He et al. [63], Fuldauer et al. [69], Sahin et al. [70], McEvoy et al. [71], Macmillan and Woodcock [72], Randhir and Raposa [77], Dearden and Wilson [84], Elliott et al. [96], Smetschka and Gaube [97], Middya et al. [107], Li et al. [108], Thondoo et al. [109], Quan et al. [110], Adamek et al. [112], Campbell and Im [116], Dembski et al. [120], Pardo-Garcia [122], Artopoulos and Costa [43], Andreani et al. [45], Moore and Elliott [73], Archetti et al. [102] |
| From databases         |                                  |                          |                                                                            |
| Sensor data            |                                  |                          |                                                                            |
Table 2. Cont.

| Phase               | Method                        | Tool                                      | Reference                                                                 |
|---------------------|-------------------------------|-------------------------------------------|---------------------------------------------------------------------------|
| Data Processing     | Model development            | Agent Based Modelling and serious games   | Voinov et al. [1], Marcucci et al. [27], Yang et al. [38], Le Pira et al. [53], Lewis et al. [57], González-Méndez et al. [61], Smajgl [88], Smetschka and Gaube [97], Drogoul [99], Silva and Novaes [113], Montalto et al. [114], Anand et al. [115] |
|                     |                               | System Dynamics                           | Voinov et al. [1], Mangano et al. [24], Stave et al. [42], Stave et al. [42], Melkonyan et al. [62], Sahin et al. [70], Sahin et al. [70], Macmillan and Woodcock [72], Hedelin et al. [89], Venturini et al. [98], Drogoul [99], Silva and Novaes [113] |
|                     |                               | Fuzzy Cognitive Mapping                   | Voinov et al. [1], Olazabal et al. [47], Firmansyah et al. [64], Smetschka and Gaube [97] |
|                     |                               | AHP                                        | Vermote et al. [80] |
|                     |                               | Machine learning model                    | Middya et al. [107] |
|                     |                               | Bayesian Networks                         | Strith et al. [92] |
|                     |                               | Discrete Choice                           | Marcucci et al. [27], Anand et al. [115] |
|                     |                               | Cellular automata                         | He et al. [63], Hewitt et al. [104], Li et al. [108] |
|                     |                               | Ontology                                   | Anand et al. [115] |
|                     |                               | GIS                                        | Nae et al. [36], Kumar et al. [39], Olszewski et al. [52], Neuenschwander et al. [53], Omidipoor et al. [67], Kariuki et al. [91] |
| Simulation          |                               | Delphi                                    | Vieira et al. [111], Quan et al. [110], Long et al. [76] |
|                     |                               | Structured Interview Matrix               | Sharifi et al. [50] |
|                     |                               |                                            | Leonard et al. [44], Fiandrino et al. [49], Shaqfat et al. [54], Sahin et al. [70], Ducrot et al. [75], Randhir and Raposa [77], Graveline et al. [78], Muste et al. [83], Gaddis and Voinov [85], Endo et al. [100], Campbell and Im [116], Dembski et al. [120], Gaudron et al. [121] |
| Optimization        |                               | NSGA II, PSO, other algorithms, etc.      | Grogan [35], Elliot et al. [96], Quan et al. [110], Adamek et al. [112], McGarity et al. [117], Ranjan [118], Hori et al. [119] |
| Backcasting         |                               |                                            | Pereverza et al. [60], Fuldauer et al. [69], Smetschka and Gaube [97], Hori et al. [119] |
| Validation          |                               | Questionnaires                            | Dembski et al. [120] |
|                     |                               | Interviews                                | Hori et al. [119] |
|                     |                               | Cross impact analysis                     | Raj et al. [94], Middya et al. [107] |
|                     |                               | Multi criteria decision analysis          | Neuenschwander et al. [53] |
|                     |                               | MACBETH                                   | Vieira et al. [111] |
|                     |                               | ETL                                       | Dierich et al. [94] |
|                     |                               | SDSS                                      | Omidipoor et al. [67] |
|                     |                               | Public participation                      | Rosol [58] |
| Workshops           |                               | Community design                          | Forlano and Mathew [56], Moore and Elliott [73], Brits et al. [79], Weimann et al. [95], Leskens et al. [103], Gaudron et al. [121] |
| Visualization       |                               | Static, AR, VR, etc                       | Khan et al. [82], Endo et al. [100], Quan et al. [110], Dembski et al. [120] |
Table 2. Cont.

| Phase            | Method       | Tool                                  | Reference                                                                 |
|------------------|--------------|---------------------------------------|---------------------------------------------------------------------------|
| Results presentation | Visualization | Graphs                                | Almost all                                                                |
|                  |              | Videos (Agent-based visualization)    | Lewis et al. [57]                                                         |
|                  |              | 3D modelling                          | Neuenschwander et al. [53], Khan et al. [82],                             |
|                  |              |                                       | Neuenschwander et al. [123]                                               |
|                  |              | Maps                                  | Yang et al. [38], Deardens and Wilson [84], Pfeffer et al. [90], Kariuki et al. [91], Strith et al. [92], Endo et al. [100], Li et al. [108] |
|                  |              |                                       | Neuenschwander et al. [123]                                               |
|                  |              | Numerical results                     | Marcucci et al. [27], Stauskis [55], Lewis et al. [57],                   |
|                  |              |                                       | Melkonyan et al. [62], Quan et al. [110], Adamek et al. [112], Silva and Novaes [113], Montalto et al. [114], Campbell and Im [116] |
|                  | Roleplaying  |                                       | Le Pira et al. [51]                                                       |
|                  |              | New tool as a result                  | Grogan [35], Leonard et al. [41], Artopoulos and Costa [43], Pardo-García et al. [44], Fiandrino et al. [49], Olaszewski et al. [52], Lewis et al. [57], Omidipoor et al. [67], Khan et al. [82], Pascaru and Pascaru [87], Hedelin et al. [89], Strith et al. [92], Strith et al. [92], Dembski et al. [120] |
|                  | Policy        |                                       | Marcucci et al. [27], Halligey [59], Pereverza et al. [60], Melkonyan et al. [62], Stanczuk-Gawlczak et al. [68], Macmillan and Woodcock [72], Gaddis and Voinov [85], Elliot et al. [96] |
|                  | recommendation|                                       | Yang et al. [38], Kuru and Ansell [40], Andreani et al. [45], Stauskis [55], Pereverza et al. [60], González-Méndez et al. [61], Omidipoor et al. [67], Beirao et al. [105], McDermott et al. [101], Ranjan [118], Caudron et al. [121] |
| Methodology       | Framework     |                                       | Yang et al. [38], Kuru and Ansell [40], Andreani et al. [45], Stauskis [55], Pereverza et al. [60], González-Méndez et al. [61], Omidipoor et al. [67], Beirao et al. [105], McDermott et al. [101], Ranjan [118], Caudron et al. [121] |
| Uncertainty analysis | Model         |                                       | Shafqat et al. [54], Smajl [88]                                           |
| Living lab        |              |                                       | Fu et al. [93]                                                            |

However, this type of data crowdsourcing involves moving to electronic databases, thus, making processes like PPGIS (voluntary public participatory GIS) possible. PPGIS is an emerging method of data collection in the conducted review.

Conventional data collection techniques such as interviews (including all forms of interviews: structured, semi-structured, and in-depth interviews) and workshops (single level, and multi level) remain an important data collection alternative while existing databases via spatial data, have emerged as the avenue for input data.

Real-time data via sensors embedded in the environment were also considered as a potential input collection approach in the review conducted. These data were directly employed in the empirical modelling using simulation and optimization techniques, as revealed in the literature review.

In the next step, we study how the forms of data processing have changed over the decade.

Data Processing

The second step of data processing in simulation-based participatory modelling is characterized by the use of computers. However, there is a gradient in the use of computational methods and computer power required to process the data. During our review, we deduced that this gradient proves to be an important factor while differentiating the various purposes for which participatory modelling was adopted.

Using a gradient in computational methods, we imply that a higher degree of computational power was required in one categorical purpose of participatory modelling. The review revealed that the computational methods varied from visualization techniques (static, augmented reality, virtual reality) to optimization methods. Visualization tech- niques mostly contribute to more conventional purposes of participatory modelling, such as, communication, while newer techniques such as optimization methods are paving the path for a new purpose in participatory modelling.
There are other conventional methods of model development that we discovered during the review, as presented in Table 2.

Output Presentation

In the last step, we present how the output from the processed data were presented in the reviewed articles, and how the output presentation depended on the purpose of participatory modelling.

We noted that Graphs were used in almost all cases and were the most common means of results presentation as mentioned in Table 2. On one end of the spectrum in cases of communication, results were presented in the form of workshops such as roleplaying, while the other end of numerical results were mostly the output of empirical modelling. Results in the form of policy recommendations were predominantly the outcome of decision-making, while a living lab in an instance in the review is used for demonstrating the knowledge generation. Methodology and frameworks were also considered as a common form of output presentation in the articles reviewed.

3. Results

We propose a categorization to capture the diversity and complexity of the participatory modelling found in the production and urban logistics literature. We take a systems approach to literature content analysis that allows us to address key interrelated components: Purpose, Outcome, Methods, and Tools. We, further, describe these key components as shown in Figure 4 based on different parameters.

The results further analyse and discuss the two main research questions: (i) Changing purpose of simulation-based participatory modelling, and (ii) Methods and techniques used in different phases of simulation-based participatory modelling. Further we discuss the sustainability perspective of the literature analyzed.

3.1. Changing Purpose of Simulation-Based Participatory Modelling

Simulation-based participatory modelling in the domain of logistics has been used in primarily three conventional approaches viz knowledge generation, communication and decision-making, together with an emerging fourth category of empirical modelling, which in our opinion is a significant advancement in the field. With our analysis, we differentiated articles and categorized them according to their purposes, as presented in Figure 3. We determined that the categorization was based on the fidelity of the data used as well as on the participants and stakeholders. We briefly read out the analysis for each purpose representing each quadrant to elucidate the categorization.

During the analysis, it was determined that the categorization could be made based on the nature of data and backgrounds of stakeholders. Further, the purpose led to one or more outcomes depending on the nature of participatory modelling. Tools and methods were observed to be overlap in all purposes; however, they are mentioned here in terms of prominence in a particular purpose.

Starting from the bottom right quadrant in Figure 4, we observed that there were 31 articles focussing on decision-making, with the data fidelity of type quantitative and results in planning and policy recommendations. The most frequent but not exclusive methods are backcasting and forecasting, with the frequently used tools mentioned in the diagram. Similarly, other quadrants can be read depending on the purpose, outcomes, tools, and methods.

In Figures 2 and 3, we see the trends in articles based on the purpose they serve in participatory modelling in the production and urban logistics domains. As can be observed in Figure 2, since 2015, there has been an increase in the articles published in the empirical modelling category that is based on analytical results, and this trend continues. This, according to the analysis done, can be attributed to the use of mathematical models and optimization techniques. In Figure 3, a general surge trend can be observed in the number of articles in the domain employing simulation-based participatory modelling.
3.2. Methods and Techniques Used in Different Phases of Simulation-Based Participatory Modelling

We synthesize results from the previous section that correspond to the second research question regarding the tools and methods used during different phases of participatory modelling [3], that is, (i) input collection, (ii) data processing, and (iii) output presentation, of participatory modelling.

We map the tools that are used based on the different phases and various purposes they serve in simulation-based participatory modelling in the domain as shown in Table 2.

For input collection, the techniques varied from conventional methods such as interviews, and workshops to newer techniques such as crowdsourcing and data collection using sensors.

As we discussed earlier, we observed an increase in the number of quantitative methods that could consequently be mapped to the new purpose of simulation-based participatory modelling. For the other purposes of participatory modelling; namely, communication, decision-making and knowledge integration the trends followed as observed in previous literature.

For output presentation, we observed that it largely depended on the recipients of the results. If the results were to be disseminated among citizens, static and dynamic visualization techniques were used whereas if the results were input to other scientific studies analyses like uncertainty analysis were considered.

3.3. Simulation-Based Participatory Modelling Studied from Sustainability Perspective

In the review, we looked at the articles and the trends of including sustainability factors in the research work. We saw there were 73 articles which included sustainability (mostly economic) in some form in their work. We only considered sustainability as a whole while looking for articles including sustainability in their work.

However, we during the review did not delve deep into how sustainability aspects by looking into economic, social and environmental sustainability perspectives. This aspect can be analyzed and described in detail in future work.
4. Discussion

Understanding the different facets and aspects of simulation-based participatory modelling can be important to both practitioners and researchers in the domain. However, the literature available today on the topic is very limited. We looked at the different literature surveys and reviews done in the domain of production and urban logistics to have a better understanding of the research landscape. We enumerate these reviews relevant to our literature survey in Table 3.

From these reviews done in the last decade presented in Table 3, we looked at the timeframe, domain, and methods employed in these articles. We saw systematic literature review in many of these articles in domains varying from logistic strategies to policies. These also included different facets of production and urban logistics spanning from freight logistics to last-mile deliveries. Lagorio et al. [124] in their review article consolidated the research done in urban logistics in from 2000–2015 thus providing insights into the state of the research. Other analyses like, bibliometric analysis and scientometric analysis were done to classify advances and trends in production and urban logistics.

Other literature surveys focus on the decision-making methods applied in sustainable urban and production logistics. Mixed methods approach, systems approach and qualitative measures, like interviews were employed to make these categorization. However, we in this article focus on simulation-based participatory modelling.

During our analysis, we found out that along with the three existing purposes, namely, communication, decision-making, and knowledge integration, there is a fourth emerging purpose of participatory modelling. We decided to call it empirical modelling. We believe that the nature of research in the field participatory modeling is changing. The increase in available computational power and improvements in simulation tools are adding a new dimension to the field. We further demonstrated the rise in the number of articles written in this category of purpose. We also discussed the different phases of participatory modelling within the domain followed by the evolving nature of methods and tools employed therein.

Table 3. Relevant reviews conducted in the domain of production and urban logistics.

| Reference | Year | Method | Timeframe | Domain |
|-----------|------|--------|-----------|--------|
| Zunder et al. [125] | 2014 | Mixed methods approach | Until 2013 | Developing a local research strategy for city logistics on an academic campus |
| Lagorio et al. [124] | 2016 | Systematic literature review | 2000–2015 | Research in urban logistics |
| Aljohani and Thompson [126] | 2016 | Systematic literature review | 2000–2015 | Impacts of logistics sprawl on the urban environment and logistics |
| Rose et al. [19] | 2017 | Systematic literature review | Until 2017 | Review of logistic strategies |
| Jamshidi et al. [127] | 2018 | Decision-making methods | 2000–2017 | Priority criteria and decision-making methods applied in selection of sustainable city logistics initiatives and collaboration partners |
| Dolati Neghabadi et al. [128] | 2018 | Bibliometric analysis | 2010–2017 | City logistics classification and analysis |
| Viu-Roig and Alvarez-Palau [129] | 2018 | Systematic literature review | 2017–2019 | Impact of e-commerce-related last-mile logistics on cities |
| Hu et al. [130] | 2019 | Scientometric review | 1993–2018 | Research trends and advances in city logistics |
| Reda et al. [31] | 2020 | Systematic literature review | 2000–2020 | Identification of the regional and economic contexts of sustainable urban logistics policies |
| Meza-Feralta et al. [131] | 2020 | Systematic literature review | 1990–2019 | Typology of urban logistics spaces as interfaces for freight transport |
| Szmelter-Janosz et al. [132] | 2020 | - | Until 2020 | Assessing resources management for sharing economy in urban logistics |
| Zunder [133] | 2021 | Semi-systematic literature review | Until 2018 | Identifying research opportunities for more sustainable, receiver-led inbound urban logistics flows to large higher education institutions |
| Arvianto et al. [134] | 2021 | Systematic literature review | 2016–2019 | Challenges and innovative solutions in developed and developing economies |
| This article | 2021 | Systematic literature review | 2010–2021 | Simulation-based participatory modelling in production and urban logistics |
5. Conclusions

During our research in the area of participatory modelling, we observed that the use of participatory modelling is increasing in all fields, which makes the elucidation of the field crucial. Because participatory modelling can be used in all fields, the scope of this study was significantly wide. Therefore, we had to reduce the scope to make an attempt to understand the particular domain of production and urban logistics. In addition to this, the use of computers has changed the landscape of many fields. We believe that the use of computers has a crucial role to play in the changing landscape of participatory modelling. Hence, this review is important. Furthermore, to the best of our knowledge no review or survey study has been conducted to either investigate the use of computers in participatory modelling or the use of participatory modelling in urban and production logistics domain. Therefore, we combined the two fields: the research work in this article, which presents the intersection between the fields: simulation-based participatory modelling in the domain.

In this article, we critically reviewed the literature in the domain of urban and production logistics using simulation-based participatory modelling in the last decade. We studied this literature and observed the effect of using high computational power in participatory modelling. The research indicates that although the old techniques of mostly qualitative research such as interviews stay prominent in the medium of performing research in the area, there is another trend emerging with the use of high computational power. We could not attribute this to any of the existing established purposes of participatory modelling in the literature. Hence, we concluded that there is an emergence of a fourth category, which is based on the use of high computational power and employs various optimization techniques. This results in more deterministic results and hence makes validation easier with the use of numerical outcomes.

5.1. Limitations

Although the literature discussed in this article surveyed four prominent databases still there is literature that is not covered by the article. This includes other databases and white papers from industry and, thus, it could be seen as a delimitation for this work and the approach adopted for the survey.

5.2. Practical and Theoretical Implications

This article primarily analyzes theory of simulation-based participatory modelling in urban and production logistics, and hence, presents theoretical implications of the research. Practical implications of the research performed during the development of this work is discussed in the article [135] by the team in which computational methods are employed for participatory modelling in the domain. This presented deterministic results which were used in decision-making and planning by various stakeholders.

5.3. Research Agenda and Future Directions

One of the major future work of this research work is validation of the proposed categorization through surveys and empirical data collection. The categorization can also be expanded depending upon the results of the validation.

In the second research agenda for the work, sustainability has a whole is discussed to a certain extent in this article. It could be worth discussing the framework and the literature with respect to triple bottomline of sustainability and making inferences hence.

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