INTRODUCTION

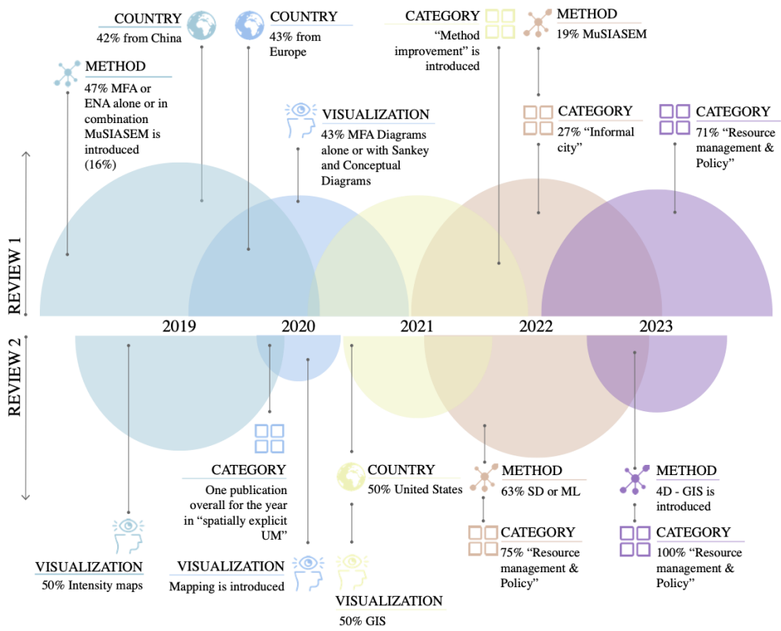
This review delves into the integration prospects of Urban Metabolism (UM) with industry 4.0 technologies, particularly digital twin (DT), to enhance sustainable urban development. Embracing a DT framework can enable the visualization of interdependencies within civil systems, facilitating the prediction of interventions to mitigate future climate change impacts.
Analysis of 70 UM studies revealed minimal integration with Industry 4.0 or DTs, with static visualization methods predominating. The research highlighted a lack of dynamic, geographically-oriented visualization in UM. An extended review showed a gap in UM-DT integration, despite increased use of mapping. We argue that integrating UM with DT can improve spatial representation and real-time contextualization, making UM more effective for urban planning and climate change mitigation.

Searching for New Urban Metabolism Techniques:

A Review Towards Future Development for a City-Scale Urban Metabolism Digital Twin

METHODS

We conducted two sequential literature reviews. In the first review, we focused on UM in the context of case studies, methods, and visualization of results (review 1 - Figure below). Consequently, recognizing the potential for integrating Industry 4.0 technologies and dynamic visualization approaches within UM analytical studies to enhance UM practices we then conducted a second review (review 2 - Figure below), that combined UM and Industry 4.0 technologies (such as the Internet of Things, Artificial Intelligence, Digital Twins, GIS, and System Dynamics). In both reviews, we classified papers in categories based on the system analyzed and the objective of the study, and we also conducted a detailed analysis of methods and visualization techniques used (see Sankey Diagram). For the purpose of this study, we maintained a focused approach to ensure depth and coherence in our analysis of UM.



RESULTS

In reviewing the literature on UM and UM use of Industry 4.0 technologies distinct trends emerged across all categories, methods and visualization techniques analyzed.

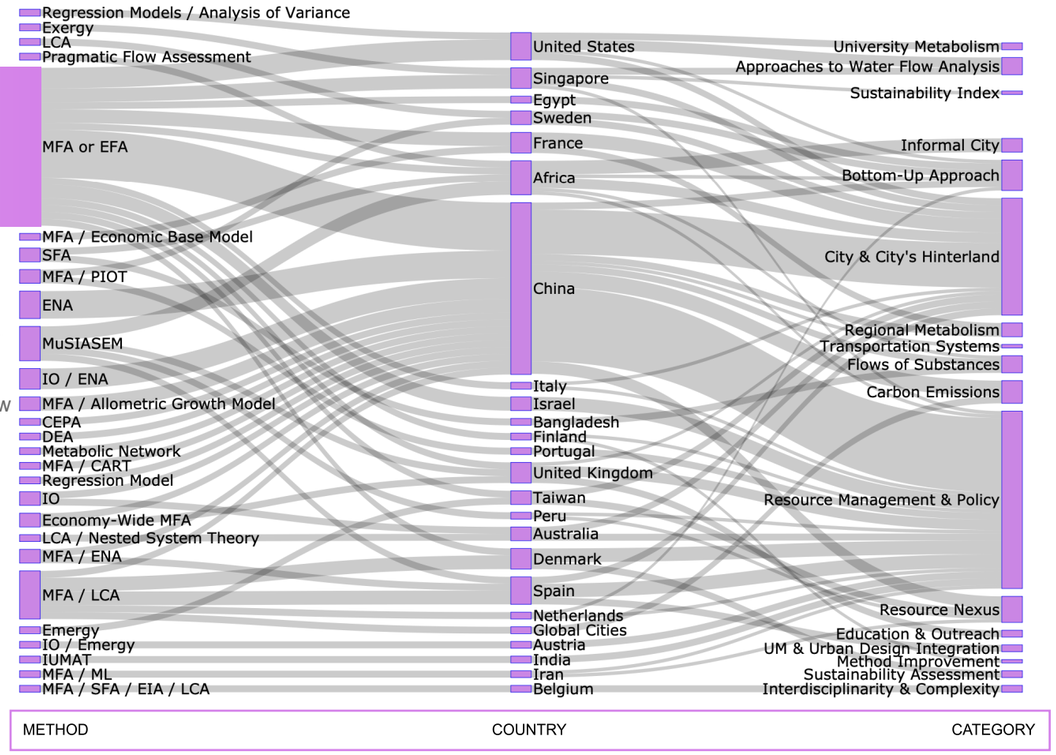
In review 1 the two main categories of "city and city's hinterland" and "resource management and policy", largely used sankey diagrams, MFA diagram, and bar diagram. The larger number of articles in this field indicated a significant emphasis on investigating the best strategies for managing and optimizing urban resources. Review 1 also revealed a predominant focus on Chinese cities, accounting for 36% of the studies, followed by European regions at 24%. This distribution underscores China's leadership in analytical UM studies conducted between 2019 and 2023. The primary objective of these studies was to create evidence for policy-making or resource management. Notably, a diverse array of methods and visualization techniques were employed, indicating ongoing experimentation and exploration within the field.

On the contrary, review 2 showcased a more balanced distribution of research efforts among Europe (20%), China (24%), and the United States which took the lead with 28% of the papers focusing on the integration of Industry 4.0 technologies into UM analysis. The exploration of various frameworks, ranging from machine learning to GIS and LIDAR usage, to SD and IUMAT, reflects the diverse research scopes within this domain. Nonetheless, spatial variables were not predominant despite their usefulness being widely recognized.

However, it's noteworthy that regions with limited resources, particularly in developing countries, were not as prominent in review 2. This observation can be attributed to the intricate nature of UM studies, which often encounter challenges related to interdisciplinary collaboration, data limitations, and insufficient financial, technical, and digital infrastructure required for advanced technology solutions.

CONCLUSIONS

From this study a common theme emerges, the need for a cohesive and dynamic representation of the outcome and methodological standardization of UM. The limited integration of UM with Industry 4.0 technologies, particularly DTs, further underscores this challenge. These results highlight the importance of advancing dynamic visualization methods and integrating Industry 4.0 technologies to bolster urban sustainability endeavors. By fostering the introduction of new technologies new insights into urban dynamics and optimized resource management strategies can be unlocked. Additionally, this holds the potential to streamline research efforts, facilitate cross-study comparisons, and foster collaboration among researchers and practitioners.



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