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# Material matters: Recommendations for the analysis of relational spaces in sociotechnical transition studies

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ABSTRACT

This article examines the interplay between materiality, relational spaces, and technological change dynamics. The objective is to introduce a novel theoretical perspective and a structured analytical process designed to enrich the investigation of relational spaces within the context of sociotechnical transitions. Our perspective aims to help transition scholars integrate the often-overlooked importance of material arrangements with the analysis of material flows and social components. We interpret this integration as a morphological approach to the analysis of relational spaces. The development of our perspective is grounded in a thorough review of existing literature on transition studies, complemented by the application of the theory of space constitution. Through our theoretical contribution, we advance the spatial discourse in transition studies, offering the means required to produce novel insights into how diverse social and material dimensions of spatial contexts affect, and are affected by, sociotechnical transition pathways and the technological change they produce.

## 1. Introduction

In the last decade, the discourse on space within sociotechnical transitions has advanced significantly, largely in response to a call for greater contextual awareness and appreciation for scale and agency in technological change processes [1–4]. The field of human geography has played a crucial role in this evolution [5], nurturing the growth of a vibrant research community dedicated to exploring the Geography of Sustainability Transitions (GOST) [6]. Concurrently, research on urban transitions has begun to explore the socio-spatial dimensions of sociotechnical transitions, underscoring the importance of local action in urban settings [7]. Arising predominantly from these two streams of literature is an emerging conceptualization of relational space within transition studies. Researchers argue that the relational space is not merely a backdrop but is actively constructed through the interplay between actors, materials, and cultural practices [1,8]. This body of work has been instrumental in expanding the initial focus on national contexts that characterized transition studies, broadening the scope to examine how transitions occur across various spatial scales, including cities, neighborhoods, and, more recently, households [9,10].

In this literature, however, the analysis of the material components of relational spaces tends to be approached in a reductionist manner compared to the social dimension (actors and cultures). Evidence of this omission is highlighted by Hansen and Coenen [11], who examined the initial development of the GOST literature. Their work points out that the primary goal of this literature is to capture "the distribution of different transition processes across space" (p. 95). To understand this distribution, transition scholars have been examining how the characteristics of different relational spaces influence transition processes and technological changes. However, Hansen and Coenen's [11] study reveals that relational spaces are predominantly compared by examining socio-cultural and political relationships rather than material components, which tend to be overlooked. We contend that this omission stems from the limitations of the analytical approach currently in use.

This analytical approach can be illustrated by looking at literature on urban transitions. Here the material dimension of relational spaces is examined mainly through the lens of *material flows*, interpreted as the movement and circulation of material components within a relational space [7,12,13]. When adopting this perspective, understanding how materiality makes a relational space unique involves analysing the interplay between multi-scalar material flows and socio-political dynamics [14]. Interpreting materiality as flows is important for capturing the processes that shape relational spaces. However, this perspective leaves out the analysis of *material arrangements* [15] – the spatial

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distribution of material objects in relational spaces – and how they form perceivable surroundings for everyday life [16,17]. A notable exception is urban energy landscapes research [18].

Recognizing this limitation, our objective is to advance the discourse on relational space within sociotechnical transition studies. Grounded in a critical examination of the theoretical frameworks in sociotechnical transition studies, we elucidate the intricate interplay between materiality, relational space, and transition dynamics that generate technological change. Our discussion is instrumental in introducing a novel theoretical perspective and a structured analytical process that can help sociotechnical transition studies to harmonize their established emphasis on material flows and social dynamics with the hitherto overlooked significance of material arrangements. Viewed through the multidisciplinary lens of physical geography, human geography, and urban studies, this integration can be interpreted as a *morphological analysis of relational spaces* [19].

By introducing a morphological perspective in the analysis of relational spaces, we contribute to addressing multiple challenges inherent in sociotechnical transition studies. First, morphological analyses can enhance our comprehension of "how spatial contexts matter" [20] in sociotechnical transitions, responding to a persistent demand for clarity [1,11]. For example, morphological analyses can support a nuanced examination of sociotechnical transition processes, overcoming the limitations of examinations based on place-making, place-framing, and sense of place, which tend to neglect the significance of material arrangements [8,21–23]. These interrelations have already been established in other disciplines like environmental psychology, geography, and architecture, underscoring the value of morphological insights [24–28]. Second, the examination of how urban fabric characteristics either facilitate or hinder sociotechnical transitions remains largely unexplored in urban transition studies [6]. Investigating the interplay between material arrangements and sociotechnical transition processes could reveal critical attributes, facilitating comparisons across different scales from the broad landscapes [29,30] to individual households [9]. Third, a morphological perspective is instrumental in advancing research on socio-ecological transition models [31,32]. It can serve as a pivotal link between human and physical geography, bridging a notable gap in the analysis of socio-ecological transitions [33,34].

This article is structured into three main sections. The first section introduces the *theory of the constitution of space*, providing a foundation for the morphological analysis of relational spaces in sociotechnical transitions. This theory is central to our argument because it explains how materiality and relational spaces connect to sociotechnical change. The second section addresses the methodological challenges of applying our morphological perceptive on relational space in empirical research. The third and final section highlights the theoretical and practical implications of our study.

## 2. The theory of the constitution of space: integrating material and relational dimensions with sociotechnical change

Initial efforts to explore the interplay between materiality and relational space in sociotechnical transitions can be found in the energy transition studies by Becker et al. [35]. Their work identifies key theoretical frameworks crucial for conducting research that is attuned to both spatial and material dimensions in sociotechnical transitions. These frameworks include Foucauldian dispositives, assemblage urbanism, Urban Political Ecology (UPE), and the strategic-relational approach. Becker and his team highlight the utility of Foucauldian dispositives in unveiling the ways material arrangements can shape power dynamics. Assemblage urbanism offers insights into the formation of sociomaterial assemblages[1] by encompassing a diverse array of human and non-human actors without presuming a predefined hierarchy among them. Through a broader, multi-scalar perspective, UPE can be instrumental in examining the creation of material environments, including their flows and arrangements, from a critical realist standpoint that emphasizes fluidity and reconfiguration. Lastly, the strategic-relational approach provides a lens to examine how social structures, social relations, and agency evolve over time, identifying structures[2] that are either conducive or resistant to change.

We expand the array of possible theoretical frameworks proposed by Becker et al. [35] by incorporating the theory of the constitution of space [36]. This addition is motivated by three main reasons. First, Löw's theoretical formulation bridges the gap between the analysis of material objects and the discourse on the interplay between structure and agency. It builds upon and elaborates Giddens' [37] structuration theory, which serves as the ontological base for the multi-level perspective on sustainability transitions [38], by elucidating the role of material objects in the formation of structures. Löw conceptualizes relational space as a configuration of social goods and individuals, where social goods possess both material and symbolic attributes. These relational spaces evolve into institutionalized structures as the arrangements of people and material objects gain stability through established routines. Löw argues that changes in these structures occur when spaces are radically transformed through collective action. Her theoretical formulation implies that material objects can drive social and technological transformations through the emergent properties of structures. This implication aligns with emerging critical realist conceptualizations of material agency[3] in sociotechnical transitions studies [39–41], which acknowledge that structures have material components [42,43] and can condition[4] human action [44], thus exerting an indirect influence on transition dynamics. As we will explain in the following paragraphs, Löw's theory contributes to advancing the discussion on material agency by elucidating the processes through which the material and social dimensions co-constitute such structures.

Second, Löw's theory explains *how* materiality contributes to the constitution of relational space, articulated through the interplay of two distinct yet concurrent processes: the placing of people and material objects within a relational space through practices (*spacing*), and their interconnection via perception, imagination, and memory (*synthesis*). Her investigations underscore the importance of viewing the social and material dimensions as intertwined elements of relational spaces, rather than as discrete and independent entities. Within the context of sociotechnical transitions, spacing refers to the changes induced by transition processes, such as the creation, elimination, transformation, or repositioning of material objects, and alterations in the spatial arrangement of people. This perspective allows for the examination of how relational spaces are formed through both everyday practices (see also Castán Broto, 2019; [45]), and strategic interventions (e.g., the introduction of a new building or amendments to planning regulations). Synthesis is

[1] According to Deleuze and Parnet [91], an assemblage is "a multiplicity which is made up of many heterogeneous terms and which establishes liaisons, relations between them".

[2] The term *structures* refers to the underlying arrangements of elements within a sociotechnical system that is undergoing a transformation [42,92,93]. A sociotechnical system is composed of social, economic, political, technological, environmental, organizational, and cultural structures.

[3] We adopt a Latourian (2005) [96] interpretation of agency, which regards it as the ability of both human and non-human entities (including actors, actants, and structures) to influence the trajectory of events, thereby playing a role in social transformation [17,94,95]. This definition is selected for its comprehensive inclusion of both human and non-human forms of agency.

[4] Conditioning is one of the phases of Archer's [44] morphogenetic cycle of social change, alongside social interaction and structural elaboration. This phase involves providing a framework that can either enable or constrain actions without entirely dictating them.

shaped by individuals' evolving perceptions of their material surroundings engendered by transformational processes. These shifts in perception may stem from the emergence of new actors, the modification or introduction of material objects, or novel interactions between actors and both new and existing objects (see also [46]). By focusing on perception, synthesis highlights the significance of lived experiences as a crucial bridge linking relational spaces with societal transformations.

Finally, the theory of the constitution of space helps understand *why* material flows and material arrangements should be examined together, introducing the need for morphological analyses; it considers the examination of material objects' arrangements as complementary to flow-centric investigations [47]. Löw contends that the scrutiny of material arrangements and flows is interconnected, advocating for their exploration to occur in tandem within the analytical process. Drawing from Sturm [48], she introduces a methodological framework for analyzing relational spaces, encompassing four phases: (1) the mapping of individuals and goods within a relational space, (2) synthesis, (3) spacing, and (4) the observation of emerging structures. Initially, the process focuses on deciphering the relational space's form, elements, and appearance. Attention then shifts towards understanding how individuals perceive this space and the meanings they attribute to it. Subsequently, the inquiry examines the dynamics governing the placing of individuals and objects, which are influenced by both institutionalized practices and individual actions. The final stage of analysis contemplates the capacity of the relational space to nurture social stability and catalyze social change.

To illustrate how this methodological framework can operate within transition studies, we present a hypothetical morphological analysis. The aim of the analysis is to assess the influence of the materiality of relational spaces on transition dynamics in an urban neighborhood. The neighborhood scale is chosen as our illustrative example for two main reasons. First, neighborhoods are commonly analyzed for material transformations [49,50]. Second, they serve as relevant testbeds for localizing international transition agendas, such as the European Green Deal [51].

In the mapping phase of the morphological analysis, the study should capture the material arrangements of the neighborhood, including its buildings, natural environment, infrastructure networks and arrangements of people and other objects. This phase also implies mapping the actor networks relevant to the transformation. Importantly, mapping material objects should not be observed only from a two-dimensional perspective. Urban morphology studies [52] have long established that capturing building heights, volumes, materiality, and styles is crucial for a comprehensive understanding of the urban fabric.

The synthesis phase follows, with an exploration of how different actors perceive the neighborhood, which material elements (such as a local cinema or a highway overpass) are most significant in shaping these perceptions, and whether these perceptions converge into collective place identities.

The spacing phase should focus on the processes that shape the arrangements identified during the mapping phase. Examples of these processes include, but are not limited to, neighborhood masterplans and urban design projects, traditional building and waste management practices that define material flows, and collective routine behaviors like eating outside on the main street or parking in courtyards.

In the final phase, which involves observing emerging structures, the analysis will focus on how the characteristics of the relational space identified in the previous three phases are established sufficiently to limit alternative actions and behaviors. It will also examine which characteristics remain more fluid. This analysis should reveal how the neighborhood might enable or constrain the implementation of transition strategies, or whether alternative transition pathways might be more appropriate.

## 3. Connecting relational space and transition dynamics

Applying Löw's theory within sociotechnical transition studies requires the development of methodological approaches that synergistically analyze material flows, material arrangements, and social dimensions. To our knowledge, such an integrative approach has yet to be adopted in sociotechnical transition studies that focus on relational spaces. We therefore encourage scholars in the field of transitions to explore this research gap. A possible solution might involve leveraging and adapting methodologies already utilized in examining various space dimensions within sociotechnical transitions. For instance, we consider the potential of drawing upon Arena of Development (AoD) research [53], place-framing methods [1,8], and the historical analysis of transitions [38,54–57]. Our selection highlights methods and tools that predominantly focus on material arrangements, a facet that has been relatively underexplored in sociotechnical transition research in comparison to material flows.

The concept of AoD pertains to cognitive spaces that encapsulate the settings and relationships underpinning transition processes. These settings include "actors, artifacts, and standards that populate the arena, a variety of locations for action, knowledge and visions that define the changes of this space, and a set of translations that has shaped and played out the stabilization and destabilization of relations and artifacts" ([53], p.410). While artifacts form an integral part of these arenas' ontology, empirical investigations have predominantly focused on their social dimensions [58,59].

Informed by Löw's theoretical perspective, transition scholars may benefit from employing the AoD concept to facilitate the integration of analyses concerning the evolution of actor-networks during sociotechnical transitions with the understanding of how material arrangements and flows influence these interactions. Valderrama Pineda and Jørgensen's [60] study provides preliminary evidence of this potential to introduce morphological analyses of relational spaces. Their investigation into the transformative effects of the Copenhagen metro system contributes to clarifying the intertwined roles of social dynamics and material arrangements in the technological transformation of urban environments. By analyzing space components through qualitative data gathered from interviews and archival records, their work sheds light on the significance of material arrangements. Although their research does not explicitly focus on material flows, it reveals the importance of viewing artifacts from the perspective of actors within the arena, thereby uncovering the material environment in which the transition takes place. This analytical approach is in line with Castán Broto's (2019) recommendations, which propose that within the AoD framework, material environments should be understood not as strictly local but as entities that evolve alongside actor networks.

Significant methodological advancements are also presented by Sharp et al. [22] in a study that showcase the utility of place frames in enhancing the analysis of material environments. Place frames are defined as "partial representations or visions of what a place is or could become" ([8], p.84) as a result of a sociotechnical transition process. Sharp and colleagues conduct an analysis of four competing place frames within the context of the net-zero transition of the Monash Technology Precinct in Melbourne. Their examination highlights the perspectives of key actors involved in the transition process, focusing on the existing components of the precinct's material environment. Linking to Löw's theory, we can interpret this step of the analysis as an interesting way to approach synthesis (see Section 3).

Sharp et al. [22], along with Valderrama Pineda and Jørgensen (2016), demonstrate that the study of material arrangements can be conducted by examining the accounts of the actors involved in sociotechnical transition processes. However, these studies tend to be limited to snapshots at specific moments within these processes. In contrast, Roberts and Geels [61] underscore the significance of longitudinal analyses that trace the evolution of material arrangements and flows throughout transitions. This more comprehensive examination is critical

for the final phase of Löw's analytical process, focusing on the emergence of structures. To overcome this limitation, Roberts and Geels [61] suggest an in-depth exploration of transitions' historical development (see Ref. [62]).

For example, Leontidou [63] combines the analysis of spatial transformation and socioeconomic change to scrutinize Athens' transition from feudalism to capitalism from 1948 to 1981. This exploration delves into the relationships among material arrangements, the spatial distribution of social classes, and the underlying socioeconomic dynamics. By juxtaposing various snapshots of material environments corresponding to significant socioeconomic milestones within this timeframe, the analysis uncovers the dynamics between systemic changes and material environment transformations.

## 4. Conclusion

In this article, we examined the connections between materiality, relational spaces, and sociotechnical transition dynamics. Through an investigation of the intersections between Löw's constitution of space theory and sociotechnical transition studies, our argumentation led to the development of a new theoretical perspective. This perspective is designed to help transition scholars examine relational spaces in sociotechnical transitions by integrating their established emphasis on social components and material flows with the overlooked significance of material arrangements. From an analytical perspective, this integration can be interpreted as a morphological examination of relational spaces. Furthermore, we propose a structured process for conducting these morphological analyses. Inspired by Löw's theoretical contributions, this approach encompasses four phases: (1) the mapping of individuals and goods within a relational space, (2) synthesis, (3) spacing, and (4) the observation of emerging structures. The four phases are presented in Table 1, which also includes several key elements: theoretical streams in sociotechnical transitions (Column 3) and external to this domain (Column 4) that share the analytical focus of each phase; and a list of disciplines with proved experience in the different phases of morphological analyses, highlighting where cross-disciplinary research practices can inspire growth in transition studies (Column 5).

From an empirical viewpoint, incorporating a morphological approach into the analysis of relational spaces could support the creation of taxonomies for spatial contexts within the framework of sociotechnical transitions, as well as enable comparative studies on the impact of their social and material components on transition processes. An initial attempt to develop these taxonomies is offered by Larondelle et al. [64], who categorized physical locations based on their potential to either support or impede sociotechnical transitions in Rotterdam's urban fabric. Sociotechnical transition studies have long recognized the significance of contextual variances on the processes of transition, as evidenced by research comparing the dynamics of sociotechnical transitions across different settings—such as developed versus developing regions, urban versus rural areas, and urban centers versus peripheries [65–67]. By conducting morphological analyses of relational spaces, it may become possible to identify further nuances pertaining to the material aspects of relational spaces, such as the comparison between densely and sparsely built urban areas, historical versus contemporary urban fabrics, or countries characterized by building stocks with different ages.

Moreover, calling for more attention to material environments in transition studies can also become a vehicle for further cross-disciplinary collaborations in this knowledge domain. It encourages scholars from disciplines like environmental psychology, ecology, architecture, physical geography, and art to engage closer with transition studies and contribute hitherto unexplored perspectives.

From a practical standpoint, the application of our analytical approach has the potential to guide decision-making processes in sociotechnical transitions and urban experimentation by offering insights into the impact of material environments on different transition pathways. This understanding is particularly pertinent to the field of transition design [68–70], which investigates the role of design-led strategies in managing transitions [71].

Finally, it is important to highlight the potential challenges of conducting morphological analyses in transition studies, as awareness of these challenges can inform future research. First, there is limited

**Table 1**
Phases of morphological analyses. Adapted from Löw [36] and Sturm [48].

| Phase | Analytical focus | Theoretical connections | | |
|---|---|---|---|---|
| | | Sociotechnical transition theory | Other theoretical perspectives | Potential cross-disciplinary bridges |
| Mapping | Material arrangements | • Energy landscapes (Castán Broto, 2017)<br>• Social-ecological-technological transitions [31]<br>• Arenas of development [53] | • Theory of urban form [77]<br>• Space syntax [78] | • Architecture<br>• Earth science<br>• Physical geography<br>• Sustainability science<br>• Urban studies |
| Spacing | Material flows and social practices | • Political ecology approach to urban transitions (Castán Broto and Bulkeley, 2013)<br>• Energy landscapes (Castán Broto, 2017)<br>• Practices in transitions [79] | • Social practice theory [80]<br>• Political ecology [81,82] | • Anthropology<br>• Architecture<br>• Earth science<br>• Human Geography<br>• Physical Geography<br>• Political Ecology<br>• Sociology<br>• Sustainability science<br>• Urban Studies |
| Synthesis | Perception of space | • Socio-psychological analyses of relational spaces in transitions [16]<br>• The role of culture in transitions [83]<br>• Place frames [21,22],<br>• Energy landscapes (Castán Broto, 2017)<br>• Just transitions [84]<br>• Sociotechnical imaginaries [85,86]<br>• Design for sustainability transitions [68] | • Place identity [87]<br>• Technology acceptance model [88] | • Anthropology<br>• Architecture<br>• Environmental psychology<br>• Phenomenology |
| Emergence of structures | Institutionalisation of relational spaces and their capacity to condition human action | • Causality in transitions [39,41]<br>• The structuration of socio-technical regimes [89]<br>• . | • Structuration theory (Giddens, 1994)<br>• Morphogenetic approach [44]<br>• Institutional theory [90] | • Organization studies<br>• Sociology |

understanding of the ecological factors that influence the constitution of spaces. Morphological analyses could play a crucial role in advancing the study of relational spaces within social-ecological-technological transitions [31,72], due to their connection with physical geography. However, these analyses build on Löw's constitution of space theory, therefore, they are predominantly formulated to examine the processes that create material arrangements through social practices (spacing). To better integrate our morphological perspective into the literature on social-ecological-technological transitions, further research is needed to determine how the conceptualization of spacing can include ecological processes, such as those caused by natural cycles or the behaviors of non-human species.

Second, more clarity is needed to understand whether our four-phase analytical approach can be used to examine the constitution of spaces with hybrid arrangements connecting virtual and physical dimensions. How does the virtual dimension influence the analytical approach? Research in urban studies and organizational studies has pointed out that, to understand sociotechnical change, this virtual dimension should be analyzed as part of relational spaces and not in isolation [73], and it should be conceptualized as an interplay of material and social components [74]. The theory of the constitution of space has already been used for investigating the constitution of hybrid relational spaces [75], but it has revealed that a more nuanced understanding of the nature of structures might be needed [76].

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**Ioannis Lykouras:** Writing – review & editing, Writing – original draft, Conceptualization. **Luca Mora:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

## Data availability

No data was used for the research described in the article.

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