Geoforum 165 (2025) 104378

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

What can the bamboo industry learn from timber? Resource mobilization across global innovation systems in the construction sector

Francesca Mazzoni [a,b], Christian Binz [c,d], Sebastian Losacker [b,d,*]

[a] Social Sciences Area, Gran Sasso Science Institute (GSSI), L'Aquila, Italy
[b] Department of Geography, Justus Liebig University Giessen, Giessen, Germany
[c] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
[d] CIRCLE – Centre for Innovation Research, Lund University, Lund, Sweden

ARTICLE INFO

Keywords:
Global innovation system
Bio-innovation
Sustainability transitions
Construction sector
Bioeconomy

ABSTRACT

In the scholarly literature on the geography of transitions, the global innovation systems framework has been used to understand how system resources—such as knowledge, legitimacy, markets, and financial investments—are linked across various geographical scales, contributing to the emergence and performance of an innovation system within a distinct technological field. In this paper, we further develop and adapt the conceptualization of global innovation systems to the case in which system resources of a focal innovation system are mobilized from adjacent innovation systems, building on the literature on technology interactions. Empirically, we demonstrate how multi-scalar resource mobilizations between two innovation systems emerge in the case of the evolving spatially sticky innovation system of bamboo building technologies, which draws system resources from the more mature market-anchored innovation system of timber building technologies. We find that the bamboo system mobilizes legitimacy, knowledge, and market resources from the timber system in a commensal relationship, meaning that the bamboo system benefits while the timber system is not affected by the interaction. Given the footloose nature of knowledge resources in the timber system, compared to the system's spatially sticky valuation-related resources, the former are more easily mobilized across systems than the latter. Moreover, we posit that the distinct spatial anchoring of both systems hinders further cross-system resource mobilization. Our paper contributes to geographical innovation and transition research by providing a conceptual lens for understanding resource mobilization across innovation system boundaries.

1. Introduction

Given that the construction sector is a major contributor to global carbon emissions, transitioning towards more sustainable modes of building and housing is crucial. The integration of bio-based materials, and in particular of bamboo, in the construction sector can significantly lower its carbon footprint (Amiri et al., 2020; Churkina et al., 2020; Mishra et al., 2022). Bamboo is, in fact, among all bio-based materials used for constructions, the one with the highest carbon storage potential (Liu et al., 2022). During its rapid growth cycle, bamboo sequesters large amounts of carbon dioxide from the atmosphere, locking it away in its biomass. Utilizing bamboo in construction not only prevents the stored carbon from being released, but also reduces reliance on carbon-intensive materials like steel and concrete. Moreover, bamboo stands out as the fastest growing plant on the planet, capable of reaching maturity in just 3–5 years compared to the decades required for traditional timber. This rapid growth rate allows for quicker replenishment and a sustainable supply of construction materials (Liu et al., 2022; Xiao, 2022).

As global demands for bio-based construction materials surge, novel materials made from bamboo offer a viable and sustainable solution to meet these needs without depleting natural resources, particularly in Asia, South America and parts of Africa, where bamboo is indigenous and abundantly available (Göswein et al., 2022). Bamboo material innovations therefore have the potential to play a significant role in reducing the construction sector's greenhouse gas emissions and to lead its transition towards a bioeconomy. However, while certain bio-based materials are already well-established and widely adopted for construction worldwide, as in the case of timber, bamboo remains instead relatively underutilized. Currently, bamboo is in the nascent stages of its

* Corresponding author at: Department of Geography, Justus Liebig University Giessen, Giessen, Germany.
E-mail address: sebastian.losacker@geogr.uni-giessen.de (S. Losacker).

https://doi.org/10.1016/j.geoforum.2025.104378
Received 6 February 2025; Received in revised form 18 July 2025; Accepted 31 July 2025
Available online 12 August 2025

development as a construction material. Its full potential is yet to be realized, and it has not yet reached the same level of legitimacy nor integration within the global construction industry as timber (Xiao, 2022).

With this paper, we intend to analyze the interactions between two innovation systems, namely timber construction technologies and bamboo construction technologies. Both are simultaneously challenging the dominant sectoral regime in the construction sector, which is drawing heavily on CO_2-intensive materials such as steel and concrete. In particular, we aim to explore how far the emerging bamboo innovation system can draw on system resources from the adjacent, yet more mature, timber innovation system in order to expand and fully develop. We do so by building on and further developing the global innovation system (GIS) framework (Binz & Truffer, 2017), and specifically by more deeply conceptualizing how system resources can be mobilized not only across places and scales within a given system, but also across two adjacent innovation systems.

The GIS framework has been introduced to the geography of innovation and sustainability transitions literature to better assess the multi-scalar innovation system formation dynamics observed in many technology fields, with different system resources such as knowledge, markets, legitimacy, or investments emerging in various places and on different geographical scales (Ayrapetyan et al., 2025; Binz et al., 2012, 2014; Dewald & Fromhold-Eisebith, 2015). Although the GIS framework has been further refined in recent years (Heiberg & Truffer, 2022; Rohe, 2020; Tsouri et al., 2021), existing studies have remained pre-occupied with assessing system resource formation dynamics within one single system. What has remained lacking is an exploration of how different GIS may interact with each other and mutually reinforce or block each other's innovation trajectories. With this paper, we aim to address this gap by further conceptualizing and empirically illustrating the cross-system resource formation processes that may support the development and growth of an emerging (global) innovation system, like the one for bamboo-based construction materials. We accordingly ask: How can an emerging GIS mobilize system resources in interaction with adjacent innovation systems?

While our analysis draws on the innovation systems literature, it is situated within a broader sustainability transition perspective. Rather than viewing bamboo construction as simply the outcome of market-driven selection processes, we approach it as part of a mission-oriented transition pathway aiming to decarbonize construction, which requires strategic coordination, legitimacy-building, and public sector support. In this view, the role of the state and other institutional actors is not merely to respond to market signals but to actively shape emerging sectors through targeted procurement, regulation, and capacity-building. In China, for example, the bamboo industry receives strong support from both national and local governments through R&D funding, subsidies, and regulatory measures. The development and maturation of a bamboo-based construction materials industry is thus seen as a systemic process, in which actors with complementary expertise have to coordinate and strategically align their innovation activities.

The empirical part of the paper is based on a qualitative content analysis of a rich set of expert interviews with stakeholders in the (bamboo) construction sector, complemented by expansive desk research of relevant (grey) literature. This analysis sheds light on the resources of the global bamboo innovation system as well as its links to the timber innovation system. In doing so, it provides actionable recommendations for policymakers and regional development actors seeking to foster sustainability transitions in carbon-intensive industries like construction. Our findings contribute not only to theoretical debates on innovation systems but also to real-world efforts to promote inclusive, low-carbon industrial development in both the Global South and North.

The remainder of the paper is structured as follows. In Section 2, we motivate our conceptual lens, briefly introduce and explain the global innovation systems framework, after which we conceptualize cross-system resource mobilizations, building on the literature on technology interactions. In Section 3, we provide information on the data and methods. In Section 4, we offer a brief description and background on the case, including an overview of the structure and configuration of the bamboo and timber innovation systems. Section 5 presents the main results of our study, first showcasing how resource formation occurs within the bamboo innovation system and, second, examining the extent to which and how it draws on resources mobilized from the timber innovation system. Section 6 discusses the broader conceptual contributions of the study, outlining inroads for future research. Most notably, it proposes that the ease and success of cross-system resource mobilization depends on the (mis)alignment between the innovation and valuation modes of the systems involved. Section 7 concludes by highlighting how these findings inform both innovation theory and policy, with practical recommendations for supporting sustainability transitions in bio-based construction industries.

2. Background literature and theoretical framework

This paper builds on and contributes to the geography of sustainability transitions and innovation literature (Binz et al., 2020, 2025; Truffer et al., 2015). In transitions research, the innovation systems framework is a widely used conceptual approach for studying how new industries around 'green' technologies emerge, develop and diffuse and thereby contribute to socio-technical change towards sustainability (Bergek et al., 2008, 2015; Binz & Truffer, 2017). Especially TIS (technological innovation system) literature has analyzed in depth the structures and processes that lead to the development and maturation of more sustainable industrial paths in specific cities, regions and countries (Grillitsch & Hansen, 2019; Steinböck & Trippl, 2023; Trippl et al., 2020). Yet, TIS literature has for a long time been preoccupied with innovation trajectories that evolved within given territorial containers and sectoral boundaries (e.g. the Swiss biogas TIS, the German solar PV TIS or the TIS for offshore wind in the UK) (Binz et al., 2014). In this paper, we want to transcend these containerized notions by developing a conceptual framework that allows explaining how multi-scalar and cross-system innovation dynamics support the development of a new green industrial path like bamboo-based construction. To this end, our conceptual framework draws on the (global) innovation systems literature (Binz & Truffer, 2017), which we enrich with literature on technology interactions (Sandén & Hillman, 2011) to conceptualize how two distinct innovation systems—in our case, the bamboo construction innovation system and the timber construction innovation system—interact, and how one system may draw system resources from the other. This conceptual expansion is arguably of key importance to develop a more capacious understanding of how multi-scalar and multi-system dynamics condition how and where green innovation comes about (or not) and contribute to a sector's broader sustainability transition.

2.1. A primer on global innovation systems

In innovation studies, the notion of an innovation system acknowledges that innovation is the outcome of complex systemic interactions between different actors with complementary competencies (Dosi, 1988; Kline & Rosenberg, 1986; Lundvall, 1992; Nelson & Winter, 1977). An innovation system is understood to be more than the sum of its parts, generating emergent outcomes like knowledge formation, mobilization of financial investments, policy shifts, or the creation of supportive institutional settings, that jointly drive innovation (Bergek et al., 2015). The innovation systems perspective has been used to explain the innovation capabilities of countries and regions (Cooke et al., 1997; Lundvall, 1992), as well as the emergence and diffusion of innovations in sectors and technology fields (Carlsson & Stankiewicz, 1991; Malerba, 2002). The difference in these approaches lies in the delineation of system boundaries, with a focus either on geographical boundaries or on those stemming from the technological characteristics of the innovation. As insights on the multi-scalar formation of innovation systems have surged (Binz et al., 2012, 2014; Dewald & Fromhold-Eisebith, 2015), Binz & Truffer (2017) have introduced the notion of a global innovation system (GIS), which takes into account both the technological specificity and the spatiality of innovation systems, viewing them through a multi-scalar lens.

GIS conceptually consist of subsystems where four types of system resources are generated—i.e. knowledge, financial investment, market structures, and technology legitimacy—that are all necessary conditions for innovation to develop and diffuse. These subsystems are not defined or delimited by specific territorial units, but by the actor networks and institutional contexts involved in the formation of the respective system resources. While in some cases subsystem boundaries can align with national or regional borders, in other cases they can also form networks that transcend these borders. The development of a GIS then fundamentally depends on whether and how well the resource formation processes in the subsystems are coupled to one another. These structural couplings have been conceptualized as connections between subsystems that can get established by the actors, networks, and institutions crossing the different subsystems within a given GIS (Tsouri et al., 2021). Examples comprise transnational companies connecting knowledge developing in one region with markets in another one (actor-based coupling), the emergence of a global technology standard which aligns firms', investors' and regulators' expectations about key performance indicators (institutional coupling), or establishing regular meetings at international conferences where representatives from academia, firms, investors, NGOs and regulators exchange knowledge (network coupling) (Binz & Truffer, 2017; Tsouri et al., 2021).

The structure and development of a GIS are also influenced by the specific characteristics of the technology or industry it is developing (Agutu et al., 2024; Huenteler et al., 2016; Jayaweera et al., 2025). These characteristics, in turn, impact the spatiality of system resource formation dynamics. The innovation characteristics considered by the GIS framework include the innovation mode and the valuation mode. Innovation mode refers to the primary method through which technology-related knowledge is generated and can be categorized into two distinct types: STI (science, technology, and innovation) and DUI (doing, using, and interacting) (Binz & Truffer, 2017; Jensen et al., 2007). STI is centered around knowledge produced through scientific research and development, typically within laboratories or academic settings. In contrast, DUI involves knowledge generated through direct and often tacit, face-to-face interactions among producers, users, and consumers. Innovations primarily based on STI tend to be supported by global, mobile knowledge networks, facilitated by collaborations that transcend multiple scales. On the other hand, innovations driven by DUI are often anchored in specific regional institutional contexts, characterized by locally embedded knowledge that requires close proximity and continuous face-to-face interaction for knowledge exchange (Alhusen et al., 2021; Friedrich & Kagel, 2025; Jensen et al., 2007).

Innovation valuation, in turn, pertains to how an innovation or technology becomes a valued product for its users (Angstmann, 2025; Carvalho & van Winden, 2018; Jeannerat, 2024; Jeannerat & Kebir, 2016), relating to what is called the *economy of qualities* (Callon et al., 2002). This dynamic is influenced by the other three system resources—markets, investments, and legitimacy—and can be distinguished into two types: standardized and customized valuation. Standardized valuation applies to products that are relatively uniform and aimed at mass markets, such as fast-moving consumer goods. These products operate within a global market, influenced by price signals, with user preferences generally aligning across different places and institutional contexts. Customized valuation, in contrast, applies to innovations that are tailored to specific customer demands in particular territorial settings, relying on symbolic valuation within local and project-based markets (Binz & Truffer, 2017). Table 1 provides an overview of the innovation system resources as outlined in the GIS framework.

The spatial resource formation patterns give rise to four generic GIS configurations. A production-anchored GIS configuration is associated with standardized valuation and a DUI innovation mode. In contrast, a footloose GIS configuration links standardized valuation and the STI innovation mode. A spatially sticky GIS configuration is characterized by innovation connected to customized valuation and the DUI innovation mode. Finally, a market-anchored GIS configuration is associated with customized valuation and the STI innovation mode. Fig. 1 visualizes the spatial patterns of resource formation and multi-scalar structural couplings for the four stylized GIS configurations.

The GIS framework, as outlined above, has served as the conceptual foundation for innovation system studies in various sectors, including research on sustainable sanitation technologies (van Welie et al., 2020), solar PV (Hipp & Binz, 2020), wind energy (Rohe, 2020; Rohe & Chlebna, 2021; Tsouri et al., 2021), biorefineries (Ayrapetyan et al., 2025), AI (Yu et al., 2022), or aquaculture (Hopp et al., 2023,2024). Furthermore, the GIS framework has been further developed to better capture temporal dimensions, shedding light on the growth, maturity, and potential decline of global innovation systems (Heiberg & Truffer, 2022). It has also been refined to examine different segments of a value chain within an innovation system, offering a more nuanced perspective on the formation of system resources across various industries (Mazzoni & Losacker, 2024; Rohe, 2020; van Welie et al., 2019). Although the GIS framework has garnered significant scholarly attention and has intellectually informed (geographical) innovation and transition research, how mobilization of innovation system resources can happen beyond the focal system's boundaries has largely been overlooked. This is particularly notable given the recent push in innovation and transition studies to explore 'multi-system dynamics' in more depth (Andersen & Geels, 2023; Löhr & Chlebna, 2023; Mäkitie et al., 2022). Given that sustainability transition processes are embedded in multi-scalar and multi-system relations, we argue that expanding the innovation system perspective beyond a closed-boundary framework enables the study of global, cross-system linkages that have so far been neglected in the literature. We contend that this cross-system perspective can provide

Table 1
Innovation system resources (based on Binz & Truffer, 2017).

System resource	Resource mobilization processes	GIS dimension	Spatiality
Knowledge	Processes generating new ideas, technologies, and innovations through activities such as R&D, education, learning, and collaboration.	Innovation mode (STI vs. DUI)	Spatially sticky (DUI) or footloose knowledge creation (STI)
Technology legitimacy	Processes through which new technologies are aligned with relevant institutions. Including the alignment of technologies with social norms, regulatory frameworks, and political agendas, which helps build trust and support for their wider adoption.	Valuation mode (customized vs. standardized)	Spatially sticky (customized) or footloose (standardized) valuation
Market access	Processes establishing and developing markets for innovations. It includes activities such as creating demand, shaping consumer preferences, and establishing (niche) market structures.		
Financial investment	Processes attracting and allocating (financial) resources to support the development and commercialization of innovations. It involves securing funding from public and private investors, venture capitalists, and/or government grants.		

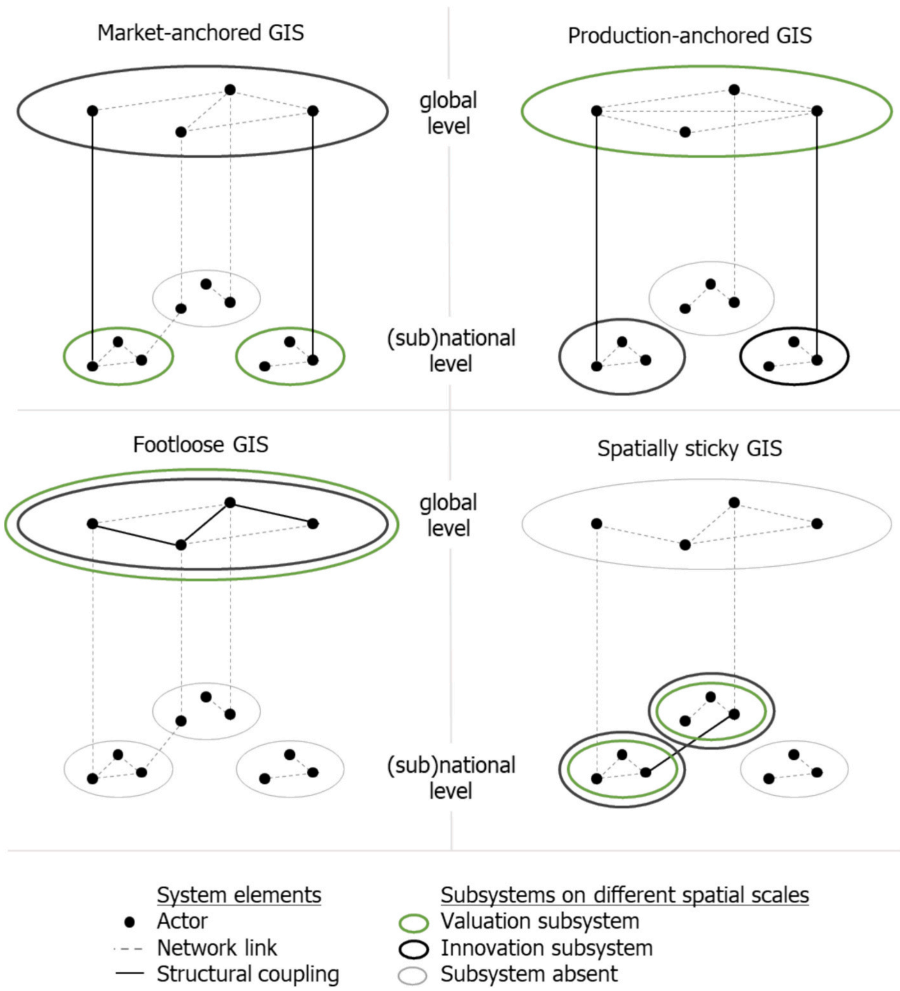

Fig. 1. Different spatial configurations of a global innovation system (based on Binz & Truffer, 2017).

important insights for sustainability transitions research and policy recommendations that are derived from it. In the next section, we thus offer some inroads into how cross-system resource mobilizations can be better understood and conceptualized.

2.2. Conceptualizing resource mobilization across innovation systems

In the geography of innovation literature, several fruitful conceptualizations exist for exploring how knowledge is mobilized across sectoral boundaries. In particular, there is a rich body of literature on combinatorial knowledge dynamics, which demonstrates how different types of knowledge (drawing on various knowledge bases) co-evolve and shape innovation trajectories (Cooke, 2007; Davids & Frenken, 2018; Strambach & Klement, 2012). Also, evolutionary economic geography has analyzed in depth how technological capabilities and skills get recombined across sectoral boundaries to induce new regional industrial trajectories (Frenken & Boschma, 2007; Hassink et al., 2019). However, this strand of literature primarily focuses on knowledge dynamics in place-based interactions, which contrasts with the concept of multi-scalar, global resource mobilizations as proposed and studied in this paper. It also tends to downplay the institutional (here: valuation-related) factors that condition how and where new industrial trajectories and innovation systems emerge or not.

To conceptualize how system resources span the boundaries of two (or more) global innovation systems, we thus draw insights from the literature on technology interactions. For a long time, innovation scholars have thought about technology interaction in highly technology-centric ways and solely in terms of competition, with multiple technological innovations struggling to become the dominant solution in a field (Abernathy & Utterback, 1978; Arthur, 1989; Pistorius & Utterback, 1997). In their seminal paper, Sandén & Hillman (2011) broadened this perspective by defining six modes of technology interaction. First, they argue that technologies can interact in a competitive manner, with negative effects for both technologies, i.e., inhibition when common resources or markets are in short supply. Second, technologies might form a symbiosis, where the interaction is favorable to both technologies. Third, technologies might interact in a way that neither affects the other, a state referred to as neutralism. Fourth, there could be an interaction the authors call parasitism, where one technology benefits and the other is inhibited. Fifth, commensalism is a mode of interaction where one technology benefits while the other is not affected. Finally, amensalism refers to the mode of interaction where one technology is inhibited and the other is not affected.

Drawing from this heuristic, several researchers have studied interactions between technologies and, more specifically, between technological innovation systems (Bergek et al., 2015; Magnusson & Berggren, 2018; Markard & Hoffmann, 2016; Ulmanen & Bergek, 2021). In a recent study, Havinga et al. (2024) find that for floating and fixed-bottom offshore wind in Norway, technology interactions create both positive and negative feedback loops. Thonig and Lilliestam (2024) show how negative legitimacy feedback from the diffusion of photovoltaics and wind power led to both policy termination and technological adaptation, transforming concentrated solar power from a generation to a storage and balancing technology. Bach et al. (2021)

demonstrate that technological alignment with the fossil fuel regime in the shipping industry provides biodiesel and liquefied biogas technologies with several benefits, such as access to established markets and infrastructure. In a related strand of literature, scholars have recently started to explore so-called multi-system interactions, aiming to better understand the various links between different sectors and how technological change in one sector affects another (Andersen & Geels, 2023; Andersen & Markard, 2020; Mäkitie et al., 2022). However, most of these studies have neglected the multi-scalar and geographically differentiated nature of how technology interactions occur. Against this background, we introduce the notion of (multi-scalar) resource mobilization between two innovation systems.

Building on the insights discussed thus far, we define resource mobilization between two distinct (global) innovation systems as the process through which one focal GIS mobilizes system resources from another GIS in order to build up and develop momentum. In this sense, the focal GIS complements endogenous system resource formation by sourcing resources exogenously from an adjacent system. Such resource mobilizations between innovation systems can take the interaction modes introduced by Sandén & Hillman (2011), where the resource mobilization might be beneficial for either only the focal system, for both, or for none, and the adjacent system might be inhibited, benefited, or not affected through the mobilization. We argue that resource mobilizations between innovation systems can form in multi-scalar and transnational ways, where, for example, a system resource for a locally emerging innovation system might be drawn from the global level of another system. As such, resource mobilizations can be conceptualized as linking two innovation systems in a multi-scalar way, with the two systems potentially having different spatial configurations. Both systems can furthermore be at the same or at different maturity levels, although typically a more emerging innovation system is likely to draw from the system resources already established by a more mature system.

In the original GIS framework, Binz and Truffer (2017) argue that structural couplings between subsystems within a focal GIS arise through actors and their networks that link two or more of the four foundational system resources, or through institutional couplings, where formal or informal institutions are created that help connect different system resources in a multi-scalar way. In a similar way, structures can also be built up at the interface of two adjacent systems that enable resource mobilization across their boundaries. This can happen through actors who connect resources between systems ('system entanglers', see Löhr & Chlebna (2023)), by establishing networks that span system boundaries, or emulating institutions developed in one system to the context of the other one. We distill all these theoretical considerations and provide a simplified visualization of our conceptual understanding of how resource mobilizations between two distinct global innovation systems occur in Fig. 2, using a market-anchored and a footloose GIS as an example.

Against the background of these conceptual elaborations, we can derive two key propositions on how cross-system resource mobilizations occur in actual empirical cases. First, we posit that the ease and success of resource mobilization are contingent on the GIS type of the adjacent system. Specifically, we argue that resource mobilization is easier for footloose innovation and/or valuation-related resources that can relatively easily be mobilized from elsewhere. In the same logic, we contend that resource mobilization is more difficult when the adjacent innovation system provides more sticky, place-bound system resources. This logic can be applied to the four GIS types: I.e., a footloose GIS will provide ample opportunities to mobilize both innovation- and valuation-related resources across system boundaries. From a market anchored GIS, STI-based knowledge can be mobilized relatively easily, especially if it is codified in publications, patents or blueprints, or manufacturing equipment. Valuation-related resources are in turn harder to transfer, as they depend on context-dependent and immobile dynamics. From production-anchored GIS, in turn, knowledge is relatively hard to mobilize (as it is embedded in territorially developed, tacit crafts and professional cultures), while valuation-related resources can be accessed relatively easily through well-structured global mass-

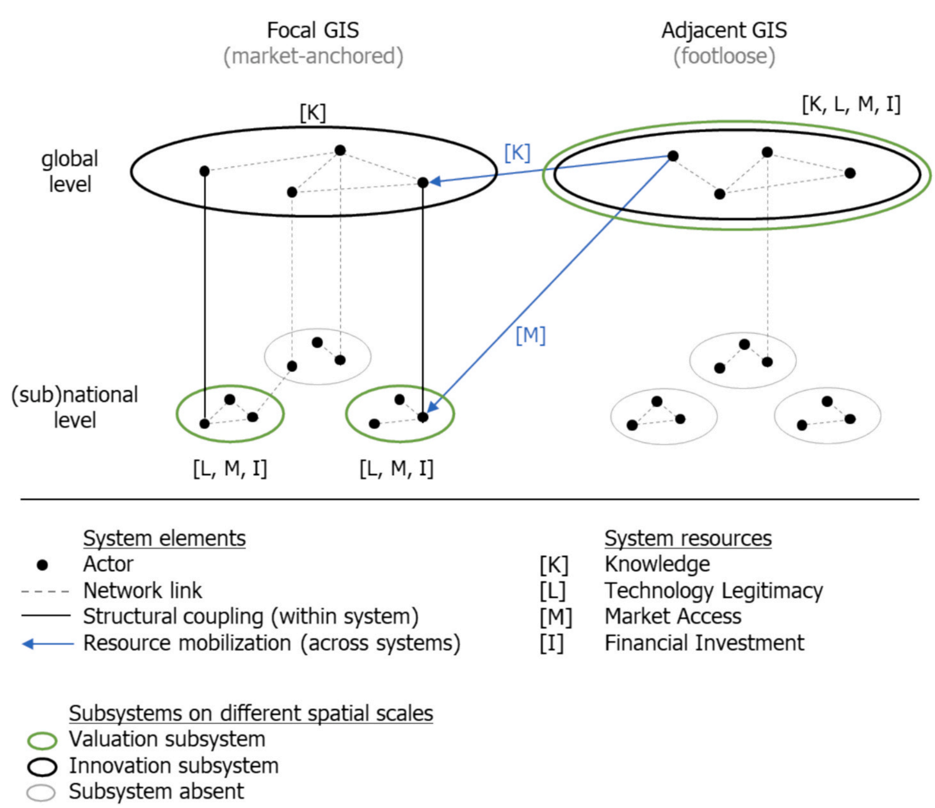

Fig. 2. Stylized example of resource mobilization across two innovation systems.

markets, globally active financial investors, or uniform product standards. Spatially sticky GIS, finally, will be most challenging to mobilize system resources from.

Second, we posit that system resources may be more easily mobilized across systems if both systems are anchored in the same regions, as spatial proximity enables more seamless transfer of territorially embedded knowledge and valuation dynamics. This is particularly relevant for tacit, DUI-based knowledge (Friedrich & Kagel, 2025) and locally customized valuation resources that can only be transferred in dense, face-to-face and contextualized exchange processes (Callon et al., 2002; Jeannerat, 2024; Jeannerat & Kebir, 2016). In the discussion in Section 6, we further explore these propositions in the context of our empirical findings.

3. Data and methods

To empirically illustrate and validate our conceptual framework, we employ an in-depth case study of the emerging bamboo construction innovation system and its interactions with the timber-based construction GIS, with a particular focus on China and India. These two countries were selected as they are the largest global players in the bamboo construction sector, thus providing most significant insights into the theoretical issues under examination. China in particular is the global leader in advanced bamboo construction technology and the biggest exporter of bamboo construction materials. Both countries are characterized by abundant bamboo resources and very dynamic construction activities, which are accelerating the exploration of bamboo uses. The case studies are complemented by additional expert interviews with stakeholders active in the bamboo construction industry globally. This approach enables a comprehensive overview of the global bamboo construction innovation system, the state of its system resource formation and the extent to which they are mobilized from the timber construction innovation system. Furthermore, to gather background information on the structure of the timber construction innovation system, we conducted extensive desk research, supplemented by additional interviews with stakeholders from the timber construction sector, specifically in Italy and Germany, as part of a large research project. We here use the timber data predominantly as background information, while the empirical analysis is focused on the data and materials collected for the bamboo innovation system.

To the purpose of our analysis, we focus mostly on larger, industrialized firms that specialize in engineered bamboo products, as they are the ones that are more likely to draw on system resources from the timber construction GIS as well as the ones that are better positioned to drive innovation, scale production, and influence market trends in the bamboo construction field. Engineered bamboo is an innovative material produced by bonding bamboo fibers, strips, or veneers through processes like lamination or compression, which enhances its strength and durability. As a result, this material exhibits properties and characteristics similar to those of timber, making it well-suited for a wide variety of structural applications in construction.

For our empirical analysis, we employed two main sources of data. First, in-depth, semi-structured expert interviews, conducted both online and in person, with stakeholders involved in the bamboo construction sector in China and India. Second, shorter semi-structured expert interviews carried out in presence at a bamboo trade fair with stakeholders active in the bamboo construction industry internationally. The latter were used to complement the in-depth interviews and to provide a comprehensive understanding of the bamboo construction GIS. The final dataset includes 30 in-depth interviews for China and India and 16 trade fair interviews, for a total of 46 interviews. The interviews used for this analysis were conducted as part of a larger research project examining the transition toward a bio-based construction sector. They were carried out by two research associates involved in the project and took place between August 2023 and November 2024. On average, the in-depth interviews lasted 70 min, with durations ranging from 45 to 100 min. While the shorter trade fair interviews lasted, on average, between 10 and 15 min.

For the in-depth interviews, a diverse range of experts was interviewed, including material suppliers, researchers, start-ups, architects, planners, engineers, and construction firms' representatives, all with substantial experience in bamboo construction. Experts were selected using a purposive sampling method, prioritizing their reputation and active engagement within the bamboo construction sector of their respective countries. This method was employed to ensure that participants provided rich insights and specialized knowledge about the bamboo construction innovation system, and its potential couplings with the timber construction innovation system.

For the shorter interviews, participants included representatives from various construction firms, such as owners, chief executive officers (CEOs), regional managers, and sales managers. These interviewees were identified based on their participation in the trade fair selected for the study and, in particular, for their involvement in the bamboo construction sector. The selected trade fair, the European Bamboo Expo 2024, was held in Dortmund, Germany, and focused specifically on advancements in the bamboo sector, attracting experts from Asia, Africa, Latin America, and Europe.

All interviews followed a semi-structured guideline. The guideline for the in-depth interviews focused on exploring the innovation system resources within the bamboo construction innovation system. While the guideline for the trade fair interviews concentrated on examining global developments and trends in the bamboo construction industry.

Most interviews were conducted in English, while some were conducted in Chinese and subsequently translated into English. The interviews were recorded, transcribed and coded using MAXQDA. We provide additional information on the interviews in Table A1 in the Appendix. To analyze the collected data, we employed a qualitative content analysis, following the principles outlined by Kuckartz (2019). In particular, we used a deductive approach in order to build the coding system, based on the GIS literature. The initial set of codes included the different system resources, namely knowledge generation, market formation, investment mobilization and legitimacy creation within the bamboo construction innovation system. For each system resource, we further identified and coded interactions between timber and bamboo innovation systems, along with the mechanisms and channels through which these interactions occur.

4. Case description

The paper examines the extent to which the emerging bamboo innovation system can draw on system resources from the adjacent, more mature timber innovation system in order to support its expansion and development. To achieve this, we begin by providing a general overview of both innovation systems in Section 4. While in Section 5 we dive deeper into the specifics of the bamboo innovation system, analyzing the state of its system resources and the degree to which they are mobilized from the timber innovation system. While both bamboo and timber construction rely on natural bio-based resources, their respective innovation systems involve largely different sets of actors, networks and institutions, and are characterized by different geographies and market dynamics, reflecting their different stages of maturity and global integration. Both systems are characterized by a complex combination of DUI and STI elements, with the timber system being comparatively more STI-focused than the bamboo one. For what concerns the valuation mode, both systems predominantly depend on rather customized valuation dynamics, with the timber system being relatively more mature and thus standardized than bamboo. In the following paragraphs we delve deeper into the specific characteristics of these two innovation systems.

4.1. Structure of the bamboo GIS

Bamboo is predominantly found in tropical, subtropical, and temperate regions, with its distribution mainly across Asia (55 %), the Americas (33 %), and Africa (11 %). China, in particular, holds the largest bamboo resources, accounting for about 20 % of the global supply (Liu et al., 2022). The market for bamboo construction is concentrated primarily in the Asia-Pacific region, especially in China, India, and Southeast Asian countries, followed by Latin America and Africa. These regions on the one hand have long-lasting experience with using bamboo in traditional building techniques and for scaffolding purposes, but on the other hand are also expected to see continued growth in 'industrial-scale' bamboo constructions due to their rising housing demands, bamboo's abundant availability, its eco-friendly benefits, and the familiarity of local experts with its use in construction. The market is also slowly expanding in North America and Europe, where increasing interest in sustainable building practices is driving the demand for bamboo-based construction materials (INBAR, 2023). China is the world's leading producer and exporter of bamboo products. In 2022, the total export value of bamboo commodities from China reached USD 2.748 billion. However, bamboo *construction materials* constituted only 2 % of these exports, translating to approximately USD 54 million (UN COMTRADE, 2024). China's primary export partners for bamboo construction materials included the Netherlands, USA, France, and Belgium. Since the early 2000s, research and development in bamboo construction has grown significantly. The top countries publishing on this topic are China, the USA, the UK, Indonesia, and India, with China leading by a considerable margin. Research funding has been predominantly provided by Chinese and UK institutions (Liu et al., 2022). In China, both local and national governments strongly support the bamboo industry through subsidies, R&D funding, and regulatory measures in the construction sector and beyond.

Therefore, the bamboo construction industry involves a spatially still rather concentrated set of actors with the majority of bamboo manufacturers and construction firms being based in China. The industry primarily comprises small to medium-sized enterprises, and some larger international players which play pivotal roles, among which we can find Dasso group and altPlus. Leading companies also exist in other Asian countries as well as the USA (e.g. Bamboo Living) and the Netherlands (e.g. BambooLogic). International organizations and advocacy groups also play a crucial role in the development of this emerging innovation system, like e.g. the International Bamboo and Rattan Organisation (INBAR). INBAR has been pivotal in promoting bamboo as a sustainable alternative to timber, developing global standards, and advocating for its integration into national building codes in countries like India and Colombia (Liu et al., 2022). This notwithstanding, gaps remain, particularly in the standardization of engineered bamboo products, which are critical for scaling bamboo's use in modern construction (Xiao, 2022). These characteristics reflect a global innovation system that is emerging and slowly expanding globally, but that is still relatively concentrated in China. Its innovation mode incorporates some elements of STI but remains more DUI-oriented and local, while its valuation mode is highly customized, with markets, investments, and legitimacy being place-bound. Its GIS configuration, therefore, appears to be predominantly spatially sticky.

4.2. Structure of the timber GIS

In contrast, timber is found in forested regions across the globe, with major timber-producing regions including North America, Europe, Asia and South America (McEwan et al., 2020). The market for timber construction is much larger and concentrated primarily in the United States, Canada, and European countries like Germany, Austria and the Nordics, due to their abundant resources, their advanced construction industries and high demand for sustainable building materials. In 2022, the United States produced around 64 million cubic meters of sawn softwood, the bulk of which is used for structural applications in residential and commercial construction (WWPA, 2023). Canada followed closely with 58 million cubic meters, with its wood product manufacturing sector – covering sawn wood and structural panels – valued at approximately CAD 19.8 billion (NRC, 2023). In Europe, Germany led with 24 million cubic meters of sawn softwood, followed by Sweden (18.9 million m^3) and Austria (10 million m^3) (EOS, 2023; UNECE, 2023). These countries are also leaders in engineered timber: Austria and Germany alone accounted for 2.84 million cubic meters of glued laminated timber (glulam) and over 1.3 million cubic meters of cross-laminated timber (CLT), both of which are used almost exclusively in construction (EOS, 2023; UNECE, 2023). These figures underscore the scale and maturity of the timber construction innovation system, particularly in engineered wood, and highlight its significance as a reference model for adjacent bio-based systems.

In particular the market for engineered timber, such as CLT and glulam, has grown significantly. These materials are enabling new forms of timber architecture, supporting the construction of taller, more complex, and more sustainable buildings (United Nations Environment Programme, 2023). Current innovation efforts within the timber GIS include high-performance glulam with improved fire resistance and load-bearing capacity, bio-based adhesives replacing synthetic resins, and hybrid timber systems that integrate structural wood with materials like concrete or steel. Moreover, advances in digital design, robotic manufacturing, and prefabricated modular systems are streamlining timber construction and increasing its appeal across various markets. Austria and Germany are at the forefront of this kind of innovation. The biggest exporters of timber for construction purposes in 2022 were Austria with USD 1.2 billion and Canada with USD 650 million, followed by Germany and Finland (UN COMTRADE, 2024). Research and development in timber construction focuses particularly on engineered wood products and sustainable forestry practices. Leading countries in timber construction research include the United States, Canada, Germany, Austria and Finland. Research funding for timber construction has been primarily supported by national governments, private sector investments, and international organizations. Notable examples include programs like Horizon Europe, which fosters innovation and sustainability in construction across the EU, and Canada's Green Construction Through Wood (GCWood) initiative, which promotes the development and demonstration of advanced mass timber technologies.

The timber industry features a more standardized and established network of actors, including large forestry corporations, global certification bodies such as the Forest Stewardship Council (FSC), and multinational timber suppliers for the construction industry, such as Binderholz or HS Timber Group. These actors operate within a well-defined global framework supported by decades of institutional experience and robust trade networks. Moreover, the timber industry benefits from long-established institutional support, including mature certification systems like FSC and PEFC (Programme for the Endorsement of Forest Certification), which ensure sustainable forestry practices. Timber construction also enjoys widespread regulatory acceptance, supported by building codes and standards in nearly every country. These characteristics reflect a more mature and established global innovation system in comparison to the bamboo system. Its innovation mode incorporates some elements of DUI but remains more STI-oriented and globalized than the bamboo system. Similarly, its valuation mode, while still being predominantly customized and region-specific, appears to be comparatively more standardized and globalized than that of bamboo. Its GIS configuration, therefore, is found to be mainly market-anchored.

As highlighted by this brief overview of the timber and bamboo construction industries, they constitute two different GIS types, each characterized by unique geographies, markets, set of actors, networks and institutions. While the bamboo GIS is still in an emerging stage, the timber GIS is way more mature and established, which could potentially provide support to the emerging bamboo innovation system in order for it to expand and fully develop. The two systems are also geographically somewhat segregated with the bamboo industry and markets being concentrated in Asia, while the timber industry is dominated by (North) American and European actors and markets. Given both systems' spatially rather sticky GIS types, this segregation is likely to pose particular challenges in cross-system resource mobilization happening across long distances. We provide a visual representation of the GIS configuration for the two systems in Fig. 3, and an overview of the system features in Table 2.

5. Results

In this section, we delve deeper into the characteristics of the emerging bamboo construction innovation system. First, Section 5.1 provides a detailed overview of the current state of its system resources – namely knowledge generation, legitimacy creation, market formation, and investment mobilization – highlighting their specific characteristics and geographic patterns. Subsequently, Section 5.2 explicitly addresses the processes of cross-system resource mobilization, illustrating how each system resource is influenced by interactions across the timber and bamboo innovation system, emphasizing the mechanisms and channels through which this process occurs, and how this is supporting (or hindering) the development and expansion of the emerging bamboo construction innovation system.

As the bamboo construction innovation system is slowly expanding globally, Section 5.1 uses a global lens to describe its system resources. However, as its industry and market are still mostly anchored and concentrated in China, Section 5.2 focuses strongly on how this cross-system resource mobilization is happening in China.

5.1. The emerging (global) bamboo construction innovation system

5.1.1. Knowledge

Knowledge on bamboo construction is created through research, experimentation and innovation, especially with regard to engineered bamboo. Moreover, practical knowledge is generated also through hands-on experience, development of novel construction techniques, and product testing. The majority of knowledge creation occurs in China, where bamboo research and practical experiments are most advanced. However, the knowledge developed there often faces delays in reaching other countries and is not always easily accessible. European countries and the US are increasingly involved in innovative research

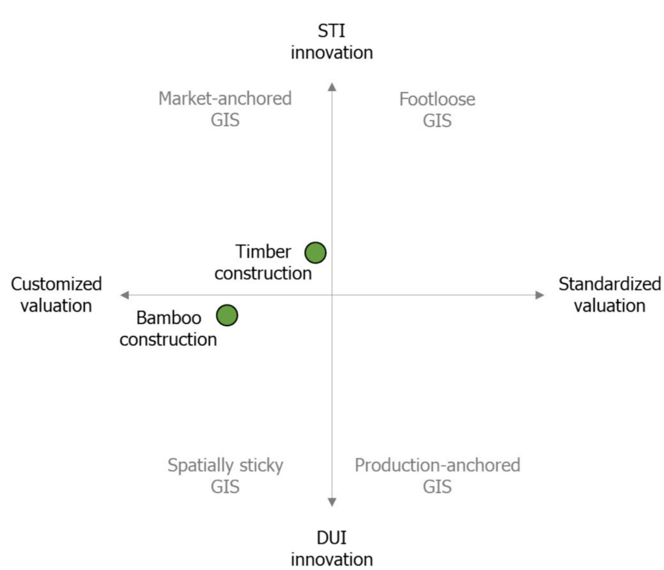

Fig. 3. GIS configuration of bamboo construction technologies and timber construction technologies.

Table 2
Overview of the timber and bamboo innovation systems.

System features	Timber innovation system	Bamboo innovation system
Actors, networks, institutions	• Many actors and their networks contribute to system building, including advanced research institutes working on timber construction research, SMEs and large construction companies, wood-processing companies, national and international industry associations • The innovation system benefits on a global level from both strong formal and informal institutions, including building codes, material standards, networks, and professional culture	• The innovation system is based on few actors that form dense networks and contribute to system building. These include, in particular, entrepreneurial researchers and architects in small organizations • INBAR plays a crucial role in system development • Bamboo construction mostly lacks strong institutional support, especially in terms of formal rules, standards, and building codes
GIS configuration	• The innovation mode involves some DUI elements, but is more STI-oriented and globalized compared to the bamboo system • The valuation mode is mostly customized and region-specific, but the timber system is relatively more standardized and global compared to bamboo • The GIS configuration is predominantly market-anchored	• The innovation mode incorporates some elements of STI but remains more DUI-oriented and local • The valuation mode is highly customized, with markets, investments, and legitimacy being place-bound • The GIS configuration is predominantly spatially sticky
Maturity	• Relatively mature innovation system • Many actors contributing to system functioning	• A relatively nascent and emerging innovation system, with bamboo construction being a niche industry • Only a few actors, who are densely connected, contribute to system functioning • The level of industry maturity differs geographically, with China leading ahead
Geography	• System resources are dispersed globally, but there are concentrations in some industrialized countries, notably in Europe (Nordics, Germany, Austria), as well as in the USA and Canada	• System resources are concentrated in selected countries and regions, notably in China

projects, however they lack a strong historical engagement in bamboo research and application, which limits their progress. In India, instead, experimentation is generally taking place with lower intensity than in China. Moreover, Indian firms are more focused on frugal uses of bamboo for construction when compared to China.

> *"China is playing a major role. Maybe you can say 60 % to 80 % because they have the technology, they have an intense focus on scientific research. In India we have the resources, but we are not utilizing them as much because we are lagging behind in terms of research and development. But we are coping with it and focusing on that."* (T7)
> *"We always have the feeling that half of the knowledge stays in Asia and the other half we get a few years later [in Europe]."* (T12)

Knowledge creation and diffusion are also facilitated globally through international events, such as conferences, trade fairs, and workshops, where individuals from different countries gather to exchange ideas and expertise. Additionally, international interest groups, such as INBAR, serve as collaborative platforms, bringing together stakeholders from across the globe, which facilitate the sharing of knowledge and experiences. Finally, knowledge generation occurs also through dedicated professionals who make critical knowledge accessible by publishing construction manuals, offering training programs and implementing demonstration projects.

> *"We [a big interest group] have 50 member states, most of them are developing countries in the Global South. We work with stakeholders that are interested in using bamboo and these construction materials [also in Europe, for example the Netherlands, Switzerland, UK]. In most countries we see a lack of technologies to use engineered bamboo structures. [...] The Partners are keen to work with China to carry out research on engineered bamboo products."* (I9)

5.1.2. Technology legitimacy

Until a few years ago, skepticism and suspicion surrounding the use of bamboo in construction were prevalent, largely fueled by widespread myths and a lack of actual knowledge about the material. However, a gradual shift is occurring as awareness grows and perceptions evolve. Nowadays bamboo's advantages as a construction material are increasingly recognized due to its unique properties and sustainable characteristics. Advocacy groups, NGOs and international organizations (such as INBAR, the World Bamboo Organization and the American Bamboo Society) as well as other dedicated stakeholders, have played a crucial role in this transformation by educating, showcasing successful projects, and lobbying for bamboo, thereby enhancing its legitimacy. As bamboo gains recognition, more entrepreneurs are entering the market, increasing stakeholder confidence and driving broader adoption.

> *"We are trying to influence governments to take a decision and go for more and more bamboo construction [...] to give more support to bamboo. So that is happening. We have done more than 100 projects across the country [in China]. So, we have now success stories to tell people that yes, bamboo can be mainstream construction. Otherwise, people would never think that bamboo can be a mainstream material."* (I2)

Demonstration projects play a central role in this process of legitimacy-building, as they offer tangible evidence of bamboo's capabilities in real-world applications. For instance, in India, while experimentation remain limited compared to China, bamboo construction is slowly gaining recognition through an increasing number of high-profile demonstration projects. A striking example is the bamboo-clad Terminal 2 of Kempegowda International Airport in Bengaluru – one of the largest infrastructure projects globally to integrate engineered bamboo at scale. The project not only showcases the architectural and functional potential of bamboo, but also contributes significantly to shifting public and professional perceptions of the material. This is particularly important in countries like India, but also China and parts of Latin America, where bamboo has traditionally been viewed as a low-cost, low-quality building material. Changing these perceptions is a key challenge, and one that is already being actively addressed, also through such high-visibility demonstration projects. In contrast, in Europe, there is increasing openness to the use of bamboo as a construction material, largely due to the growing interest in topics related to sustainability and environmental protection and a growing appreciation that existing timber reserves will not suffice to decarbonize construction.

> *"In Europe and in the US, we are way more conscious of the benefits of bamboo. In tropical countries, unfortunately, there is an image of bamboo as the poor man's timber. However, I think that is changing now."* (T11)

5.1.3. Market access

The market for bamboo-based construction material is still niche and in early stages of development; however, it is experiencing rapid and steady growth, supported also by sustainability concerns and the unique characteristics of bamboo as a building material. The market for bamboo construction is mostly gaining momentum through entrepreneurial activities. Pioneer entrepreneurs enter the market with innovative ideas, driven by the promising potential of bamboo as a sustainable construction material, and engage in experimentations, mostly through ambitious pilot projects, instead of more mainstream or commercial ones. These demonstration projects often take the form of public buildings, or projects that may arise in specialized contexts, such as tourism (e.g., hotels and resorts) or that may be commissioned for display at exhibitions or fairs. These activities create models that can catalyze change, fostering greater awareness of what can be done with bamboo and encouraging further entrepreneurial actors to enter the market.

> *"We do these large public projects because they are useful for future marketing. [...] If I mention that we did a certain project, people will have a new understanding: bamboo can actually do anything."* (I15)

Despite its advantages, several barriers hinder the market expansion of bamboo construction. The high cost of bamboo products compared to conventional materials presents a significant challenge, making it less attractive for many professionals. Moreover, a lack of clear regulations and standards creates uncertainty, which in turn affects entrepreneurial activities and investments. Without well-defined standards and codes, potential entrepreneurs are more reluctant to commit, as they require a level of regulatory certainty before engaging in large-scale projects.

> *"A big role is played by governments, if they are open to the use of bamboo for construction purposes and start to regulate its use through building codes or standards, then people will also have more confidence in its use and potential."* (I29)

Market formation is geographically varied, with cultural practices, natural resource availability, and government regulations significantly shaping market development. China has made substantial progress by implementing national policies and pioneering the first national standards for bamboo construction, and by engaging in demonstration projects commissioned by public authorities. In China, the bamboo industry receives strong support from both national and local governments through R&D funding, subsidies, and regulatory measures. For instance, in 2023, the National Development and Reform Commission, together with other ministries, launched the Three-Year Action Plan for Replacing Plastics with Bamboo. The plan aims to establish an industrial system by 2025 in which bamboo-based materials serve as a primary alternative to plastic, thus significantly driving the industry's growth in China. This illustrates that strong mission-oriented policy approaches aimed at fostering the development of the bamboo innovation system exist in China (Hekkert et al., 2020; Liefner et al., 2025). Other countries, such as in the European Union, the United States, India, and parts of Latin America and Africa, are in the early stages of market formation, with milder efforts to draft regulations and encourage the use of bio-based materials, including bamboo.

5.1.4. Financial investment

Investment in the bamboo construction sector is primarily driven by governments, especially at the local and regional level. This support is crucial, as many companies in the sector rely heavily on government subsidies and on public procurement. Local and regional governments play an active role, using public funding to stimulate industry development by supporting research initiatives, attracting businesses, and leveraging local bamboo resources. Financial investment is mobilized by local public investors especially in those countries having an abundance of bamboo resources, with China being at the forefront. However, private customers, private firms, private investors, and banks also play a role in investment mobilization and financing. Still, the level of financial investment in the bamboo construction innovation system is relatively low and underdeveloped, and the system will need to raise substantive additional investments to grow and mature.

> *"I think if government cancels their funding, then a lot of companies would collapse next month, in fact. I think more than half [of Chinese bamboo construction companies] is funded by the government. If government withdraws that funding, it will be game over."* (I29)

We provide an overview of the four system resources of the bamboo innovation system and their spatiality in Table A2 in the Appendix.

5.2. System resources mobilization at the bamboo-timber nexus

In this section, we explore the cross-system mobilization of system resources from the timber construction GIS to the bamboo construction GIS. For each system resource, we examine the mechanisms at play, the channels through which resource mobilization occurs, and the current intensity of these mobilization dynamics.

5.2.1. Knowledge

Our results reveal that cross-system resource mobilization is strongest in the knowledge dimension. A first key mechanism is that the bamboo construction sector can greatly benefit from existing research on wood processing techniques. Studies, experiments, and testing conducted on wood often provide a foundational reference, with adjustments made to account for the unique characteristics of bamboo.

> *"Simply speaking, my research and my scope is to use bamboo or engineering bamboo to replace engineered timber. So that's pretty much my idea. And to some extent that made my research simple. So, all I need to do is just to copy what has ever been done for timber, that timber scholars have already done, tons of timber bending, beam testing. Only to just do some more bamboo beam bending, so then we can develop the beam design method for bamboo structure."* (I20)
> *"We learned valuable techniques from the timber industry, especially in designing and connecting panels efficiently. This knowledge has been instrumental in developing our own bamboo panels."* (I24)

In some cases, it is not only the techniques and knowledge from the timber industry that are utilized to advance the bamboo sector but also wood processing machinery. Equipment originally designed for processing wood is often adapted and repurposed for use with bamboo.

> *"In China we cooperate with some timber production company. For example, […] if we want to produce some huge structure, beam or lumber, sometimes we use their machines or use their experiments during the process because they are experienced."* (I28)

This interaction process often occurs directly through actors with expertise in wood, who begin applying their knowledge and skills to bamboo. These cross-system learning processes typically unfold as follows: Chinese students pursue studies abroad in countries such as Japan or the USA, where the wood construction industry is highly developed. Upon returning to China, they apply and adapt the tacit knowledge and competencies acquired abroad about wood construction to advance bamboo construction practices in their home country.

> *"I think to myself it's like my experience with timber, living in an environment where timber is very available [the US]. And then the opportunity to return to China and to see China has a lot of bamboo. […] So, when I returned back to China, I saw China has not plywood but ply bamboo. So, I thought maybe we can do something. And meanwhile China does not have a timber industry, I said maybe we can use the bamboo to develop something like a timber industry. So that's the meeting point to me."* (I20)

Knowledge exchanges between the wood and the bamboo construction industry also take place at trade fairs, conferences or workshops that focus on wood-bamboo construction. Moreover, these interactions happen also through the development of products and the realization of projects. In terms of projects, a notable example is the construction of the tallest engineered bamboo building to date, located in Ninghai, China, which successfully integrates both wood and bamboo. In product development, an interesting example is Cross Laminated Bamboo Timber (CLBT), an innovative material that combines bamboo with fast-growing timber species like eucalyptus, which are typically unsuitable for construction but, when paired with bamboo, create a strong and durable material.

> *"One of our research purposes is to try to utilize Chinese bamboo and Chinese domestic timber, because China now has a lot of fast growing timber species, timber forests. Five to ten years they can mature, can be used, but the quality is low. So, if we can combine those to some extent lower quality fast grown timber with bamboo, somehow, we make a compound together and maybe we can create something better. One of the products that we developed is called CLBT. So basically, like CLT is cross laminated timber developed in Germany and Austria. So, we add bamboo in there. So that's our solution."* (I20)

The above examples show that multiple channels of knowledge mobilization from the timber GIS exist. This is likely due to the GIS configuration of the timber system. The timber construction system, being predominantly market-anchored, has STI knowledge elements that are relatively easy to transfer across systems. As outlined above, the mobilization of this system resource occurs through several key channels, with some of the most significant ones being technology transfer, the repurposing of timber-processing machinery, the spatial mobility of skilled workers, the development of hybrid construction projects and products, as well as conferences and knowledge-sharing platforms. These pathways play a crucial role in facilitating the transfer of expertise and resources, enabling the bamboo construction industry to leverage existing innovations and practices, reduce costs and accelerate its growth. However, these mechanisms also bring challenges, particularly the need to adapt methods and technologies to bamboo's unique characteristics and the necessity for intensive collaboration and research across the two industries.

5.2.2. Technology legitimacy

The emerging bamboo construction GIS can draw significantly from the already well-established legitimacy of timber construction. In fact, in countries where timber has a long history as a construction material, and therefore its credibility is firmly established, it becomes easier to extend this legitimacy to other bio-based materials, including bamboo. This is because people in these countries are already familiar with the benefits and the implications of using natural and bio-based materials for construction, and are less concerned about potential issues such as mold, fire risk, and other challenges. However, in countries like China and India, where bamboo is often still seen as a 'poor material' used in low-cost construction projects, the process of building legitimacy is far more complex (see also Fischer & Losacker, 2025). In these countries, proponents of bamboo-based construction are actively working to enhance the material's legitimacy by drawing parallels with timber, through cognitive assimilation and performance benchmarking. Cognitive assimilation seeks to ease acceptance of bamboo by presenting it in a way that aligns with people's understanding of timber. This approach emphasizes the similarities between the two materials, such as their bio-based nature, structural performance, and environmental benefits. This strategy helps to build trust and familiarity within both the public and the industry. For example, educating consumers and professionals about engineered bamboo composites, such as Cross Laminated Bamboo Timber, which is similar to Cross Laminated Timber, makes bamboo feel familiar and credible, drawing on existing perceptions of timber as a reliable material.

> *"So, we look at it as kind of one element, but here [in China] it's kind of looked at as two separate things [timber and bamboo]. And so, it's better if you can show, okay, this material [wood] is more mature, there are*

many of these projects out there now. And engineered bamboo composites are very similar to those and will function similarly with different benefits and different characteristics. So, we look for legitimacy in connecting the two because it's the quickest way for someone to associate the benefits and the outcomes." (I26)

Moreover, using timber as a benchmark, therefore comparing bamboo's performance directly to timber in critical areas such as strength, durability, fire resistance, and structural behavior, positions bamboo as a proven alternative that meets or even exceeds timber's standards. For instance, conducting beam bending tests or load-bearing comparisons are used to demonstrate that bamboo's structural capabilities are similar to the timber ones, providing concrete evidence for engineers and builders to trust bamboo as a construction material.

"It is not the same material but definitely if you need some benchmarking so that cannot be steel, that cannot be plastic. So, the benchmarking will definitely be on the basis of work already done in the timber industry. We have legacy of good research work done in timber. So now we need to leverage that." (I7)

In practical terms, these strategies are being implemented through educational initiatives aimed at both consumers and professionals. The goal is to teach them that, like timber, bamboo is a natural material that shares similar characteristics, performance standards, and environmental benefits. Additionally, demonstration projects like the ones mentioned in section 5.1 are being used to showcase bamboo's potential in real-world applications. These projects can sometimes involve also hybrid materials that combine both timber and bamboo. These demonstration projects, which either compare bamboo and timber or use hybrid materials made from both bamboo and timber, are crucial in mobilizing the legitimacy that timber construction technologies have for building legitimacy for bamboo construction.

"For example, during the use, timber is going to get some fading as well. So, we are learning some experience from the timber and learning how to explain it to the customer. And since timber they have very good education to the end customer. Now the customer can understand bamboo is like timber, and it could get fading or get some little damage during the usage. Because it is natural." (128)

Overall, the main strategies to mobilize technology legitimacy from the timber system are cognitive assimilation and performance benchmarking. The primary channels through which these strategies are being implemented are educational programs and demonstration projects. Technology legitimacy is increasingly benefiting from the cross-fertilization with the timber GIS, though there remains potential for further improvement and growth. The slower progress of technology legitimacy mobilization with respect to the mobilization of knowledge, can be attributed to timber construction industry's market-anchored GIS type, which features spatially more sticky legitimation dynamics, as well as the differing geographies of the two innovation systems.

5.2.3. Market access

Market dynamics in the bamboo construction industry also show complementarities with the timber GIS. Both GISs essentially supply a quite similar market, so timber standards can be adapted to bamboo products to establish robust market frameworks. The creation of clear and comprehensive standards and codes for bamboo construction materials is likely one of the most crucial factors defining the industry's market expansion potentials. Standards are essential because they ensure safety, reliability, and consistency in material properties, which fosters market trust and enables market scaling. Without them, designers and engineers face significant challenges in confidently utilizing bamboo in construction projects. Currently, in the absence of fully developed bamboo-specific standards across the world, the bamboo industry often relies on existing timber standards as a reference. However, due to bamboo's unique properties, such as its faster growth rate, flexibility, and distinct moisture absorption patterns, its standards need to account for key differences to timber. Over time, the goal is to develop comprehensive, independent standards for bamboo, which can be achieved by referencing and building upon existing timber standards. For now, though, timber standards serve as a crucial guide, building confidence in bamboo's use and supporting its increasing market uptake.

"Before there were none [standards for bamboo construction]. So, this was a very large hindrance. We had to use the wood timber standard, which we still do, and refer to our material standards in the US, which was quite complicated." (I26)
"[What the bamboo sector can learn from the timber sector is] the code, the Chinese design code for the bamboo is not ready yet. So, most of the projects are designed without very good code. They don't have a lot of reference and things. So, the code team, the team that makes the designing codes, they learn from the code of the timber structure." (I30)

In the case of market formation, the primary cross-system resource mobilization mechanism is the emulation of timber standards. While the intensity of resource mobilization through this channel is currently substantial, there is potential for even further expansion in the future.

5.2.4. Financial investment

For what concerns financial investment, there has been limited cross-fertilization or interaction between the timber and bamboo GIS to date. As outlined above, public procurement and government support have been critical in fostering the development and expansion of the bamboo construction industry in China, so financial resource mobilization has remained spatially rather sticky. The timber construction industry's innovation patterns are in turn backed by public research grants, large market volumes in mature markets and considerable investments by landlords, banks and institutional investors. Timber's long-term success in mobilizing financial resources could in theory provide a roadmap that the emerging bamboo industry could follow, but currently, the spatial segregation of markets and the relative stickiness of financial investment patterns in the timber industry's market-anchored GIS strongly hinder this cross-system resource mobilization potential.

6. Discussion

The results above showcase that a diverse and relevant set of cross-system resource mobilization channels support the buildup of the bamboo GIS. Fig. 4 further summarizes and condenses our study's key findings, providing a stylized representation of the bamboo and timber innovation systems and how resource mobilization occurs between them. The bamboo system, as explained earlier, is spatially sticky, with both the innovation mode and the valuation mode localized and place-bound to a few selected regions, mainly in China and to some degree India. However, the figure also shows that some actors at the global level are part of the system, and that actors from regions outside China significantly contribute to system development. Yet, overall, the bamboo system is still emerging and not as mature as the timber system. In terms of cross-system resource mobilization processes, the interaction between bamboo and timber can be defined as a commensal relationship, where the bamboo innovation system benefits while the timber system remains largely unaffected (Sandén & Hillman, 2011). Cross-system resource mobilization happens particularly by mobilizing knowledge, and to a lesser degree markets and legitimacy, from the timber GIS, while interaction in terms of financial investment remain very limited. Knowledge is mobilized from timber mostly through transfers of codified knowledge in scientific collaborations and repurposing of production machinery, but also by transfers of tacit knowledge at conferences and trade fairs and in the form of returnee entrepreneurship by Chinese experts trained abroad. Additionally, the bamboo system draws on market formation processes from the timber system, primarily through the emulation of building codes and standards, where codes for bamboo construction technologies are often based on existing

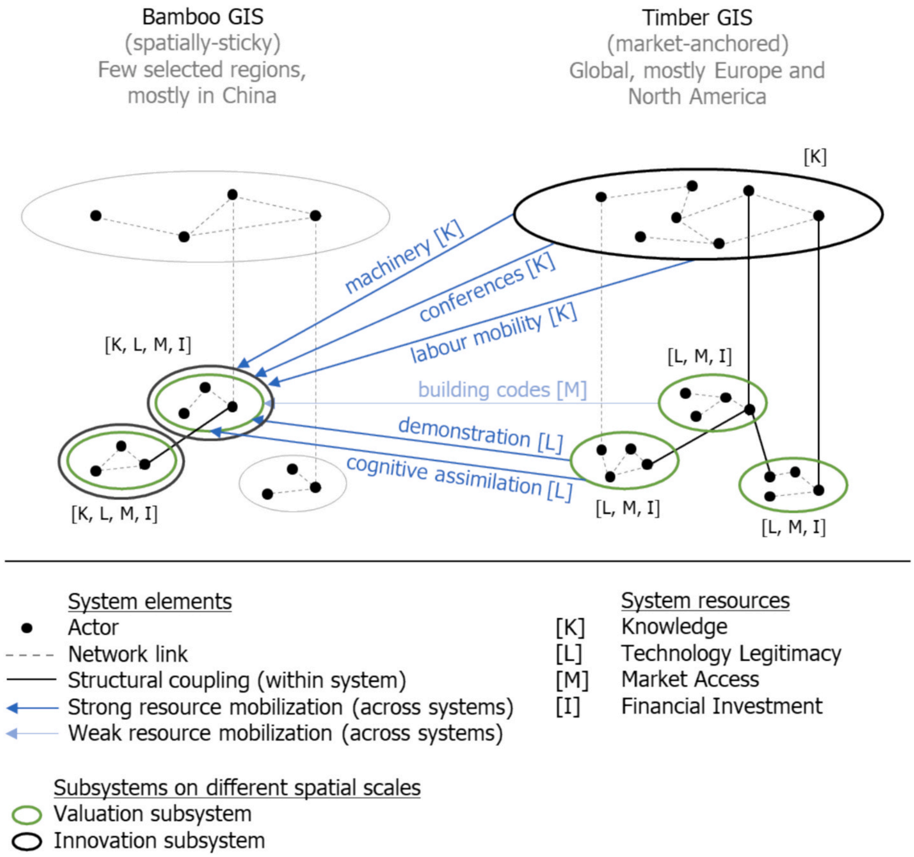

Fig. 4. Stylized representation of resource mobilizations between the bamboo and timber innovation systems.

timber codes, using the latter as templates. In terms of legitimacy, it is through cognitive assimilation and demonstration projects combining timber and bamboo which serve as cross-system resource transfer channels.

This general cross-system resource mobilization pattern largely supports the conceptual propositions developed at the end of section 2. As outlined in our first proposition, cross-system resource formation from a market-anchored GIS is much easier for the footloose knowledge-related resources than for the spatially more sticky valuation-related ones. The STI-related knowledge elements (i.e., production machinery, codified technological know-how and standardized product benchmarks) are the most easily to transfer across systems. Interestingly, our case study showed that also tacit knowledge proved transferable across system boundaries, mostly through labor mobility and returnee entrepreneurs. As expected, interlinking the spatially more sticky, valuation-related resources is much more difficult. While some transfers of market dynamics and legitimacy happen across systems, financial cross-fertilization remained mostly absent.

Regarding the second proposition, our case study supported that spatial segregation of the two systems considerably hampers cross-system resource transfer, especially for the spatially more sticky valuation processes. Mobilizing them from the timber industry would arguably be much easier if parts of this system were located in the core regions of the bamboo GIS and if local market actors had prior experience with handling industrial-scale timber products and construction techniques. An important aspect that further complicates cross-system connections here is that the two systems are located in high-income (timber: USA, Europe) vs. middle-income (bamboo: China, India) contexts. In this setup (and in today's geopolitical situation), transfer of resources is unlikely to succeed without careful translation and adaptation to local conditions. Technology transfer tends to succeed only when the imported solution is re-tailored and adapted to the local socio-economic, institutional and environmental conditions (Hanlin & Kaplinsky, 2016; Murphy et al., 2009). Local factors – such as labor and material costs, regulatory capacity, supply chain reliability, and user practices – strongly influence whether a given technology can be operated, maintained, and financed. Without this kind of contextualization, even well-established or technically advanced solutions risk to underperform, delivering limited benefits or, worse, locking firms into suboptimal practices (Jayaweera et al., 2025; Miorner et al., 2025).

Relatedly, it is important to highlight that not all actors within the bamboo construction industry benefit equally from cross-system interactions. In fact, the identified resource mobilization mechanisms are more likely to benefit firms with substantial capital, advanced technical capabilities and international networks. Large engineered bamboo manufacturers and research institutions are best positioned to leverage system resources derived from timber construction, whereas small scale, more frugal innovation-oriented enterprises may lack the resources to adopt high-end engineered technologies or navigate complex regulatory frameworks. Whether and how cross-system dynamics may reinforce the crowding out of locally embedded and more frugal-innovation focused players warrants an own research agenda in GIS literature. In addition, several avenues for further research in (geographical) innovation and transition studies emerge from this case study.

First, our results show that system resources are not mobilized in isolation from each other, but are deeply intertwined and shaped by cumulative causation patterns across global and local levels. For instance, the transfer of technical knowledge and machinery from the timber GIS to the bamboo GIS fostered technological innovation and accelerated local legitimacy-building through improved performance benchmarking and cognitive assimilation. This growing legitimacy, in turn, fed into early-stage market formation dynamics, as stakeholders began trusting bamboo as a viable alternative to timber. High-profile local demonstration projects, the development of innovative bamboo-based products like CLBT, and the formulation of bamboo product standards in turn opened an inroad to creating markets for bamboo-based construction materials in South America and Europe. Exploring these multi-scalar cumulative causation patterns in more depth would be highly promising and interesting.

Second, we could only provide initial insights into the general mechanisms that enable cross-system resource mobilization. In our case study, technology transfer processes, spatial mobility of experts, the repurposing of machinery, the emulation of standards and codes across systems, or the creation of cross-system demonstration projects were important transfer channels. Substantial further research would be needed to aggregate these channels into more general transfer mechanisms. These mechanisms may also be further related to the notion of structural couplings, as conceptualized by Binz and Truffer (2017). Further studies could explore in more depth the actors, networks, or institutions that provide structural couplings not *within*, but *across* two distinct systems.

Third, one should explore in more depth how cross-system interactions vary across the different types of technology interactions. For most of the resource mobilization processes identified in this paper, cross-system interaction is commensal, where bamboo benefits while the timber system is not significantly affected. This is most likely due to the difference in maturity of the two systems and the fact that their main markets are (still) spatially segregated. However, the situation is likely to change as the bamboo system matures. The interactions might evolve into a parasitic relationship, where the growth of the bamboo industry increasingly hampers the timber innovation system— i.e. when investments are redirected from timber to bamboo, or when bamboo enters existing timber markets. Eventually, a competitive relationship might emerge, where both systems negatively impact each other, at least with regard to certain system resources. At the same time, it is also conceivable that the decarbonization of the construction industry will lead to such a severe scarcity of biobased materials that timber and bamboo supply a rapidly growing market in a largely symbiotic relationship. They may even eventually merge into a hybrid GIS that spans both fields, as the Cross Laminated Bamboo Timber example suggests. Future research could explore in more detail how technology interactions evolve and change over time and influence whether and how cross-system resource mobilization happens.

7. Conclusion

In the scholarly literature on the geography of innovation, the framework of multi-scalar and global innovation systems has garnered significant attention in recent years (Binz & Truffer, 2017). However, the literature has so far paid little attention to how a focal innovation system can mobilize resources from adjacent innovation systems. In this paper, we contribute to filling this research gap by conceptualizing how resource mobilizations across two innovation systems can occur, building on earlier research on technology interactions (Bergek et al., 2015; Sandén & Hillman, 2011). We explore such resource mobilizations through a qualitative analysis of the interaction between the emerging innovation system of bamboo construction technologies and the more mature timber construction innovation system.

The analysis shows that the bamboo system draws resources from the timber system in a commensal relationship, where the bamboo system benefits while the timber system remains unaffected. Our findings support a basic tenet of the GIS framework, in showing that mobilizing system resources from a market-anchored GIS like timber construction is much easier for 'footloose' knowledge-related, than spatially more 'sticky' valuation-related resources. A variety of cross-system resource mobilization channels exist, ranging from knowledge transfer mechanisms to the emulation of technology standards to creating legitimizing storylines that draw on the other system's past successes. Ignoring such cross-system resource mobilization dynamics thus creates risks of misinterpreting an emerging innovation's full scaling potentials. It also risks creating policy advice with unintended knock-on effects on related sectors. While in the presented study, the relationship between the two co-evolving systems was rather commensal with the bamboo system benefiting and the timber system remaining unaffected, these relationships might be prone to more conflictual and competitive constellations in the future or in other cases.

Teasing out in more detail the co-evolution of emerging GISs, the ways in which resource mobilizations across different GIS types can be fostered and stable structural couplings be established across them, thus warrants an own targeted research agenda in innovation studies and economic geography. If the relevant complementarities can be teased out in more depth, key leverage points for speeding up innovation and transition dynamics in sustainability-related domains might be uncovered that would be of high relevance to regional and industrial policy making and theory development at once. Building on this perspective, policymakers should recognize the value of strategically supporting cross-system interactions to accelerate the development of emerging green industries. In our case, policymakers could leverage the observed synergy between the mature timber industry and the emerging bamboo construction sector by facilitating cross-system resource transfer, while ideally ensuring this support remains complementary (i.e., commensal) so as not to undermine the timber sector as bamboo markets expand. Governments and regional development agencies can facilitate this process by enabling system entanglers – such as returnee entrepreneurs, hybrid-material architects, or cross-sector researchers – through targeted funding, training programs, and regulatory frameworks. Additionally, institutional platforms such as joint standard-setting bodies, cross-industry forums, collaborative R&D initiatives, or fostering cross-system financial investments can further reduce barriers for nascent sustainable technologies, while still aligning the interests of both systems.

CRediT authorship contribution statement

Francesca Mazzoni: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christian Binz:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Sebastian Losacker:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research is an outcome of the TRABBI project at Justus Liebig University Giessen and has greatly benefited from the collaborative discussions with the entire team. We are also thankful to our colleagues responsible for conducting interviews in China (Yongmin Shang and Tim Becker), Germany (Moritz Schuetz), and India (Lennart Fischer). We acknowledge financial support from the German Federal Ministry of Education and Research (BMBF 031B1281). We also acknowledge funding from the ETH Board in the framework of the Joint Initiative SCENE (Swiss Center of Excellence on Net Zero Emissions).

Appendix

Table A1
List of interviews.

Interview name	Interviewee role	Organization country	Organization size	Organization details
In-depth interviews				
I1	Regional Director	India	Big	International organization promoting bamboo
I2	CEO	India	Medium	Supplier of bamboo and planning & implementation of bamboo construction
I3	CEO	India	Big	Bamboo advocate: R&D, architecture, education & training
I4	Managing Director	India	Medium	Supply and construction with various bio-based materials (bamboo, mud, recycled wood)
I5	Consultant & former director of a research institute	India	Medium	Research institute for bamboo construction & Advising an international interest group for bamboo
I6	Managing Director	India	Medium	Architectural firm focusing on passive and low energy architecture
I7	CEO	India	Medium	Supplier of bamboo and planning & implementation of bamboo construction
I8	Founder	India	Small	Organization focused on research and development of bamboo construction
I9	Programme Coordinator	China	Big	International organization promoting bamboo
I10	Professor	China	Medium	University, research on bio-based construction materials
I11	Professor	China	Medium	University, research on bio-based architecture
I12	CEO	China	Medium	Engineered bamboo supplier
I13	Director	China	Small	Bamboo design center
114	CEO	China	Small	Architecture company focusing on bamboo construction
I15	CEO	China	Big	Supplier of bamboo construction materials
I16	Sales Director	China	Big	Supplier of bamboo construction materials
I17	CEO	China	Medium	Architecture company focusing on sustainable, bio-based construction
I18	Professor	China	Big	University, research on engineered bamboo and timber
I19	Journalist	China	Medium	Specialized journal focused on bamboo architecture and design
I20	Professor	China	Medium	Research center for engineered bamboo
I21	CEO	China	Big	Supplier of bamboo products
I22	Sales Manager	China	Big	Supplier of bamboo building materials
I23	Sales Manager	China	Medium	Supplier of bamboo building materials
I24	Sales Manager	China	Medium	Supplier of bamboo building materials
I25	Manager	China	Medium	Architecture company focusing on bamboo construction
I26	CEO	China	Medium	Supplier of bamboo building materials
I27	CEO, Professor	China	Medium	Supplier of bamboo products
I28	Regional Manager	China	Big	Supplier of bamboo building materials
I29	Professor	China	Big	University, research on bamboo engineering
I30	Sales Manager	China	Medium	Non-profit organization promoting bio-based materials
Short trade fair interviews				
T1	CEO	Guatemala	Small	Bamboo cultivation and supplier
T2	IT/Treasurer	Ghana	Small	Non-profit organization promoting bamboo training
T3	CEO	Malawi	Small	Social impact startup integrating bamboo into agricultural communities
T4	Co-Founder	Netherlands	Medium	Bamboo farming and processing company providing carbon credits
T5	COO	China, Hong Kong	Big	Supplier of bamboo construction products
T6	Co-Founder	Uganda	Medium	Company focused on producing different kind of bamboo products
T7	Regional Program Manager	India	Big	International organization promoting bamboo
T8	Architect	Myanmar	Medium	Architecture studio specializing in bamboo construction
T9	Founder	Netherlands	Small	Bamboo supplier and training providing company
T10	CEO	Uganda, Netherlands	Small	Bamboo cultivation and construction company
T11	Founder	Panama, Netherlands	Small	Bamboo cultivation company
T12	Managing Director	Netherlands, EU	Big	Supplier of bamboo products and building materials
T13	Civil Engineer	Costa Rica	Big	Bamboo construction company
T14	Founder	Germany	Small	Bamboo construction and designer
T15	Co-Founder	Portugal, Spain	Medium	International organization promoting bamboo
T16	Editorial Director	USA	Medium	Consultancy raising awareness of bamboo as a bio-based material for construction

Table A2
Resources in the bamboo innovation system.

System resource	Description	Spatiality
Knowledge	• Knowledge on bamboo construction is created through research, experimentation, and innovation in addressing durability concerns such as mold, fungi, and weathering • Created knowledge focuses on improving bamboo's properties to match those of treated wood, making it a viable construction material	• The majority of knowledge creation occurs in China, where bamboo research and practical experiments are most advanced • China's dominance in bamboo research leads to a significant knowledge hub, but there are delays in transferring this knowledge to other countries

(*continued on next page*)

Table A2 (*continued*)

System resource	Description	Spatiality
	• Practical knowledge is generated through hands-on experience, development of construction techniques, and product testing • Academic research and industrial trials contribute to advancing knowledge about bamboo, but there are gaps in translating this into practical application along the value chain • Knowledge creation also occurs through collaboration at international events and the development of educational materials such as manuals, training programs, and demonstration projects • Challenges include the lack of formal education on bamboo for architects/ designers and insufficient training for construction workers	• European countries and the US have emerging research efforts, but their historical lack of engagement in bamboo research limits their progress • Knowledge creation is facilitated globally through international platforms such as conferences, trade fairs, and workshops, with attendees from various countries
Technology Legitimacy	• Legitimacy for bamboo in construction was historically hindered by skepticism, myths, and lack of knowledge about the material. A gradual shift is occurring as awareness increases and perceptions evolve, largely due to its sustainable properties and performance • Advocacy groups and NGOs play a pivotal role in legitimizing bamboo by educating stakeholders, showcasing successful projects, and lobbying for its use • As bamboo's legitimacy grows, more entrepreneurs are entering the market, fostering confidence among stakeholders and boosting adoption	• The legitimacy of bamboo is being recognized globally, with advocacy groups, NGOs, and governmental bodies working in multiple regions. • In Europe, there is growing openness to bamboo as a construction material, spurred by sustainability trends • In countries like China and India, bamboo is often seen as low-quality, so efforts are focused on elevating its status as a high-quality building material • Legitimacy generation is uneven, with some regions experiencing faster recognition due to more active advocacy and institutional support. • The diffusion of legitimacy is starting to happen at the global level through knowledge-sharing platforms, workshops, and conferences
Market Access	• The bamboo construction market is niche but growing, driven by sustainability concerns and bamboo's unique properties • The bamboo construction market is still in its early stages but gaining momentum through entrepreneurial initiatives • High costs of bamboo compared to conventional materials and a lack of clear regulations make it difficult for the market to grow rapidly • Entrepreneurs are entering the bamboo construction market with innovative ideas, using pilot projects to showcase its potential in public buildings and specialized contexts	• Market formation is geographically varied, with China making significant progress in policy and standards for bamboo construction • In China, Public authorities commission demonstration projects to highlight bamboo's capabilities and promote its broader adoption • Other regions, such as the EU, US, and India, are in early stages, with efforts to draft regulations and encourage the use of bio-based materials • Cultural practices, resource availability, and government regulations significantly shape market development in different regions
Financial Investment	• Investment in the bamboo construction sector is primarily driven by government funding, especially at the local and regional level • In general, financial investment in the bamboo construction innovation system is relatively low and underdeveloped	• Financial investment is mobilized especially in those countries having an abundance of bamboo resources, with China being at the forefront

Data availability

The data that has been used is confidential.

References

Abernathy, W.J., Utterback, J.M., 1978. Patterns of industrial innovation. Technol. Rev. 80 (7), 40–47.

Agutu, C., Steffen, B., Schmidt, T.S., 2024. How do technology-inherent characteristics affect valuation processes in innovation systems? Environ. Innov. Soc. Trans. 51, 100824. https://doi.org/10.1016/J.EIST.2024.100824.

Alhusen, H., Bennat, T., Bizer, K., Cantner, U., Horstmann, E., Kalthaus, M., Proeger, T., Sternberg, R., Töpfer, S., 2021. A new measurement conception for the 'doing-using-interacting' mode of innovation. Res. Policy 50 (4), 104214. https://doi.org/10.1016/j.respol.2021.104214.

Amiri, A., Ottelin, J., Sorvari, J., Junnila, S., 2020. Cities as carbon sinks - classification of wooden buildings. Environ. Res. Lett. 15 (9), 094076. https://doi.org/10.1088/1748-9326/aba134.

Andersen, A.D., Geels, F.W., 2023. Multi-system dynamics and the speed of net-zero transitions: Identifying causal processes related to technologies, actors, and institutions. Energy Res. Soc. Sci. 102, 103178. https://doi.org/10.1016/J.ERSS.2023.103178.

Andersen, A.D., Markard, J., 2020. Multi-technology interaction in socio-technical transitions: how recent dynamics in HVDC technology can inform transition theories. Technol. Forecast. Soc. Chang. 151, 119802. https://doi.org/10.1016/J.TECHFORE.2019.119802.

Angstmann, M., 2025. From waste to value? Valuation and materiality in geographies of industrial by-product use. Prog. Econ. Geogr. 3 (1), 100034. https://doi.org/10.1016/J.PEG.2024.100034.

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-by historical events. Econ. J. 99 (394), 1161–1181.

Ayrapetyan, D., Befort, N., Hermans, F., 2025. From local markets to global legitimacy: a materialization perspective on technological innovation system's dynamics. Res. Policy 54 (1), 105130. https://doi.org/10.1016/j.respol.2024.105130.

Bach, H., Mäkitie, T., Hansen, T., Steen, M., 2021. Blending new and old in sustainability transitions: technological alignment between fossil fuels and biofuels in Norwegian coastal shipping. Energy Res. Soc. Sci. 74, 101957. https://doi.org/10.1016/J.ERSS.2021.101957.

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Trans. 16, 51–64. https://doi.org/10.1016/J.EIST.2015.07.003.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res. Policy 37 (3), 407–429. https://doi.org/10.1016/J.RESPOL.2007.12.003.

Binz, C., Coenen, L., Frenken, K., Murphy, J.T., Strambach, S., Trippl, M., Truffer, B., 2025. Exploring the economic geographies of sustainability transitions: commentary and agenda. Econ. Geogr 101 (1), 1–27. https://doi.org/10.1080/00130095.2024.2445530.

Binz, C., Coenen, L., Murphy, J.T., Truffer, B., 2020. Geographies of transition—from topical concerns to theoretical engagement: a commentary on the transitions research agenda. Environ. Innov. Soc. Trans. 34, 1–3. https://doi.org/10.1016/j.eist.2019.11.002.

Binz, C., Truffer, B., 2017. Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. Res. Policy 46 (7), 1284–1298. https://doi.org/10.1016/j.respol.2017.05.012.

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems - mapping global knowledge dynamics of membrane bioreactor technology. Res. Policy 43 (1), 138–155. https://doi.org/10.1016/j.respol.2013.07.002.

Binz, C., Truffer, B., Li, L., Shi, Y., Lu, Y., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. Technol. Forecast. Soc. Chang. 79 (1), 155–171. https://doi.org/10.1016/j.techfore.2011.08.016.

Callon, M., Méadel, C., Rabeharisoa, V., 2002. The economy of qualities. Econ. Soc. 31 (2), 194–217. https://doi.org/10.1080/03085140220123126.

Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. J. Evol. Econ. 1 (2), 93–118. https://doi.org/10.1007/BF01224915.

Carvalho, L., van Winden, W., 2018. Making waves: the valuation of innovations in San Sebastian's surf economy. Eur. Plan. Stud. 26 (1), 75–93. https://doi.org/10.1080/09654313.2017.1372369.

Churkina, G., Organschi, A., Reyer, C.P.O., Ruff, A., Vinke, K., Liu, Z., Reck, B.K., Graedel, T.E., Schellnhuber, H.J., 2020. Buildings as a global carbon sink. Nat. Sust. 3 (4), 269–276. https://doi.org/10.1038/s41893-019-0462-4.

Cooke, P., 2007. To construct regional advantage from innovation systems first build policy platforms. Eur. Plan. Stud. 15 (2), 179–194. https://doi.org/10.1080/09654310601078671.

Cooke, P., Gomez Uranga, M., Etxebarria, G., 1997. Regional innovation systems: institutional and organisational dimensions. Res. Policy 26 (4–5), 475–491. https://doi.org/10.1016/S0048-7333(97)00025-5.

Davids, M., Frenken, K., 2018. Proximity, knowledge base and the innovation process: towards an integrated framework. Reg. Stud. 52 (1), 23–34. https://doi.org/10.1080/00343404.2017.1287349.
Dewald, U., Fromhold-Eisebith, M., 2015. Trajectories of sustainability transitions in scale-transcending innovation systems: the case of photovoltaics. Environ. Innov. Soc. Trans. 17, 110–125. https://doi.org/10.1016/J.EIST.2014.12.004.
Dosi, G., 1988. The nature of the innovative process. In: G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (Eds.), *Technical Change and Economic Theory*, Pinter, pp. 221–238.
EOS, 2023. *European Organisation of the Sawmill Industry (EOS) Annual Report 2022–2023*.
Fischer, L., Losacker, S., 2025. How to build (in) the future? Legitimacy of socio-technical visions in a bio-based construction sector. Environ. Innov. Soc. Trans. 56, 100996. https://doi.org/10.1016/j.eist.2025.100996.
Frenken, K., Boschma, R., 2007. A theoretical framework for evolutionary economic geography: industrial dynamics and urban growth as a branching process. J. Econ. Geogr. 7 (5), 635–649. https://doi.org/10.1093/JEG/LBM018.
Friedrich, C., Kagel, A.S., 2025. STI and DUI modes of innovation in poorly developed RIS. Systemic failures and challenges. *European Planning Studies*. doi: 10.1080/09654313.2024.2430240.
Göswein, V., Arehart, J., Phan-Huy, C., Pomponi, F., Habert, G., 2022. Barriers and opportunities of fast-growing biobased material use in buildings. Build. Cities 3 (1), 745–755. https://doi.org/10.5334/BC.254.
Grillitsch, M., Hansen, T., 2019. Green industry development in different types of regions. Eur. Plan. Stud. 27 (11), 1–21. https://doi.org/10.1080/09654313.2019.1648385.
Hanlin, R., Kaplinsky, R., 2016. South–south trade in capital goods – the market-driven diffusion of appropriate technology. Eur. J. Dev. Res. 28 (3), 361–378. https://doi.org/10.1057/ejdr.2016.18.
Hassink, R., Isaksen, A., Trippl, M., 2019. Towards a comprehensive understanding of new regional industrial path development. Reg. Stud. 53 (11), 1636–1645. https://doi.org/10.1080/00343404.2019.1566704.
Havinga, H.C., van der Loos, H.Z.A., Steen, M., 2024. Collaboration or competition? Interactions between floating and fixed-bottom offshore wind in Norway. Environ. Innov. Soc. Trans. 52, 100872. https://doi.org/10.1016/J.EIST.2024.100872.
Heiberg, J., Truffer, B., 2022. The emergence of a global innovation system – a case study from the urban water sector. Environ. Innov. Soc. Trans. 43, 270–288. https://doi.org/10.1016/J.EIST.2022.04.007.
Hekkert, M.P., Janssen, M.J., Wesseling, J.H., Negro, S.O., 2020. Mission-oriented innovation systems. Environ. Innov. Soc. Trans. 34, 76–79. https://doi.org/10.1016/J.EIST.2019.11.011.
Hipp, A., Binz, C., 2020. Firm survival in complex value chains and global innovation systems: evidence from solar photovoltaics. Res. Policy 49 (1), 103876. https://doi.org/10.1016/j.respol.2019.103876.
Hopp, J.Z., Baeza-González, S., Sjøtun, S.G., 2024. Identifying multiple configurations in global innovation system (GIS): lessons from the salmon farming industry. Eur. Plan. Stud. 1–19. https://doi.org/10.1080/09654313.2024.2424904.
Hopp, J.Z., Coffay, M., Lindfors, E.T., 2023. Inclusion in the global innovation system for CRISPR salmon in Norway. Norsk Geografisk Tidsskrift - Norwegian J. Geogr. 77 (1), 10–20. https://doi.org/10.1080/00291951.2023.2197622.
Huenteler, J., Schmidt, T.S., Ossenbrink, J., Hoffmann, V.H., 2016. Technology life-cycles in the energy sector — technological characteristics and the role of deployment for innovation. Technol. Forecast. Soc. Chang. 104, 102–121. https://doi.org/10.1016/J.TECHFORE.2015.09.022.
INBAR, 2023. Trade Overview 2022: Bamboo and Rattan Commodities in China.
Jayaweera, R., Losacker, S., Song, L.T., Schwede, D., 2025. Regional preconditions and sustainability transition pathways: Insights from circular, bio-based and resource-efficient building material innovations in Vietnam. Energy Res. Soc. Sci. 125, 104133. https://doi.org/10.1016/J.ERSS.2025.104133.
Jeannerat, H., 2024. Let's innovate! but for what value(s)? Towards an economic geography of valuation in markets and society. Prog. Econ. Geogr. 2 (2), 100022. https://doi.org/10.1016/J.PEG.2024.100022.
Jeannerat, H., Kebir, L., 2016. Knowledge, resources and markets: what economic system of valuation? Reg. Stud. 50 (2), 274–288. https://doi.org/10.1080/00343404.2014.986718.
Jensen, M.B., Johnson, B., Lorenz, E., Lundvall, B.A., 2007. Forms of knowledge and modes of innovation. Res. Policy 36 (5), 680–693. https://doi.org/10.1016/J.RESPOL.2007.01.006.
Kline, S.J., Rosenberg, N., 1986. An overview of innovation. In: Landau, R., Rosenberg, N. (Eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*. National Academy Press, pp. 275–305.
Kuckartz, U., 2019. *Qualitative Text Analysis: A Systematic Approach*. Springer, Cham, pp. 181–197, 10.1007/978-3-030-15636-7_8.
Liefner, I., Brueck, C., Losacker, S., Zeng, G., 2025. What can mission-oriented innovation policy learn from China? Sci. Public Policy 00, 1–13. https://doi.org/10.1093/SCIPOL/SCAF023.
Liu, K.W., Xu, Q.F., Wang, G., Chen, F.M., Leng, Y.B., Yang, J., Harries, K.A., 2022. *Contemporary bamboo architecture in China*. In: *Contemporary Bamboo Architecture in China*. Springer, Singapore. https://doi.org/10.1007/978-981-16-8309-1.
Löhr, M., Chlebna, C., 2023. Multi-system interactions in hydrogen-based sector coupling projects: system entanglers as key actors. Energy Res. Soc. Sci. 105, 103282. https://doi.org/10.1016/J.ERSS.2023.103282.
Lundvall, B.-A., 1992. National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning. Pinter.
Magnusson, T., Berggren, C., 2018. Competing innovation systems and the need for redeployment in sustainability transitions. Technol. Forecast. Soc. Chang. 126, 217–230. https://doi.org/10.1016/J.TECHFORE.2017.08.014.
Mäkitie, T., Hanson, J., Steen, M., Hansen, T., Andersen, A.D., 2022. Complementarity formation mechanisms in technology value chains. Res. Policy 51 (7), 104559. https://doi.org/10.1016/J.RESPOL.2022.104559.
Malerba, F., 2002. Sectoral systems of innovation and production. Res. Policy 31 (2), 247–264. https://doi.org/10.1016/S0048-7333(01)00139-1.
Markard, J., Hoffmann, V.H., 2016. Analysis of complementarities: framework and examples from the energy transition. Technol. Forecast. Soc. Chang. 111, 63–75. https://doi.org/10.1016/J.TECHFORE.2016.06.008.
Mazzoni, F., Losacker, S., 2024. What hinders the transition towards a bio-based construction sector? a global innovation system perspective on its value chain. Prog. Econ. Geogr. 2 (2), 100023. https://doi.org/10.1016/j.peg.2024.100023.
McEwan, A., Marchi, E., Spinelli, R., Brink, M., 2020. Past, present and future of industrial plantation forestry and implication on future timber harvesting technology. J. For. Res. 31 (2), 339–351. https://doi.org/10.1007/s11676-019-01019-3.
Miorner, J., Schelbert, V., Binz, C., 2025. How transformative innovations travel: tracing the diffusion of circular district-scale sanitation systems in Europe. Econ. Geogr 101 (2–3), 93–121. https://doi.org/10.1080/00130095.2025.2489965.
Mishra, A., Humpenöder, F., Churkina, G., Reyer, C.P.O., Beier, F., Bodirsky, B.L., Schellnhuber, H.J., Lotze-Campen, H., Popp, A., 2022. Land use change and carbon emissions of a transformation to timber cities. Nat. Commun. 13 (1), 4889. https://doi.org/10.1038/s41467-022-32244-w.
Murphy, H.M., McBean, E.A., Farahbakhsh, K., 2009. Appropriate technology – a comprehensive approach for water and sanitation in the developing world. Technol. Soc. 31 (2), 158–167. https://doi.org/10.1016/J.TECHSOC.2009.03.010.
Nelson, R.R., Winter, S.G., 1977. In search of useful theory of innovation. Res. Policy 6 (1), 36–76. https://doi.org/10.1016/0048-7333(77)90029-4.
NRC, 2023. *Natural Resources Canada (NRC). State of Canada's forests: Annual report 2023*.
Pistorius, C.W.I., Utterback, J.M., 1997. Multi-mode interaction among technologies. Res. Policy 26 (1), 67–84. https://doi.org/10.1016/S0048-7333(96)00916-X.
Rohe, S., 2020. The regional facet of a global innovation system: Exploring the spatiality of resource formation in the value chain for onshore wind energy. Environ. Innov. Soc. Trans. 36, 331–344. https://doi.org/10.1016/j.eist.2020.02.002.
Rohe, S., Chlebna, C., 2021. A spatial perspective on the legitimacy of a technological innovation system: Regional differences in onshore wind energy. Energy Policy 151, 112193. https://doi.org/10.1016/j.enpol.2021.112193.
Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res. Policy 40 (3), 403–414. https://doi.org/10.1016/J.RESPOL.2010.12.005.
Steinböck, N., Trippl, M., 2023. The thorny road towards green path development: the case of bioplastics in Lower Austria. Reg. Stud. Reg. Sci. 10 (1), 735–749. https://doi.org/10.1080/21681376.2023.2244572.
Strambach, S., Klement, B., 2012. Cumulative and combinatorial micro-dynamics of knowledge: the role of space and place in knowledge integration. Eur. Plan. Stud. 20 (11), 1843–1866. https://doi.org/10.1080/09654313.2012.723424.
Thonig, R., Lilliestam, J., 2024. Cross-technology legitimacy feedback: the politics of policy-led innovation for complementarity in concentrating solar power. Environ. Innov. Soc. Trans. 52, 100884. https://doi.org/10.1016/J.EIST.2024.100884.
Trippl, M., Baumgartinger-Seiringer, S., Frangenheim, A., Isaksen, A., Rypestøl, J.O., 2020. Unravelling green regional industrial path development: regional preconditions, asset modification and agency. Geoforum 111, 189–197. https://doi.org/10.1016/j.geoforum.2020.02.016.
Truffer, B., Murphy, J.T., Raven, R., 2015. The geography of sustainability transitions: contours of an emerging theme. Environ. Innov. Soc. Trans. 17, 63–72. https://doi.org/10.1016/J.EIST.2015.07.004.
Tsouri, M., Hanson, J., Normann, H.E., 2021. Does participation in knowledge networks facilitate market access in global innovation systems? the case of offshore wind. Res. Policy 50 (5), 104227. https://doi.org/10.1016/j.respol.2021.104227.
Ulmanen, J., Bergek, A., 2021. Influences of technological and sectoral contexts on technological innovation systems. Environ. Innov. Soc. Trans. 40, 20–39. https://doi.org/10.1016/J.EIST.2021.04.007.
UN COMTRADE, 2024. *International Trade Statistics*. http://comtrade.un.org/.
UNECE, 2023. *United Nations Economic Commission for Europe (UNECE) Forest products annual market review 2022–2023*.
United Nations Environment Programme, & Y. C. for E. + A, 2023. *Building Materials and the Climate: Constructing a New Future*.
van Welie, M.J., Boon, W.P.C., Truffer, B., 2020. Innovation system formation in international development cooperation: the role of intermediaries in urban sanitation. Sci. Public Policy 47 (3), 333–347. https://doi.org/10.1093/scipol/scaa015.
van Welie, M.J., Truffer, B., Yap, X.S., 2019. Towards sustainable urban basic services in low-income countries: a Technological Innovation System analysis of sanitation value chains in Nairobi. Environ. Innov. Soc. Trans. 33, 196–214. https://doi.org/10.1016/J.EIST.2019.06.002.
WWPA, 2023. Western Wood Products Association (WWPA). Lumber Track: Statistical summary of U.S. softwood lumber production.
Xiao, Y., 2022. *Engineered bamboo structures*. In: Engineered Bamboo Structures. CRC Press. https://doi.org/10.1201/9781003204497.
Yu, Z., Liang, Z., Xue, L., 2022. A data-driven global innovation system approach and the rise of China's artificial intelligence industry. Reg. Stud. 56 (4), 619–629. https://doi.org/10.1080/00343404.2021.1954610.