

Vertical Cities in Motion: Maglev Elevator Systems as Foundational Infrastructure for Arcological Urban Development

Abstract

Arcology—the integration of architecture and ecology into dense, self-contained urban megastructures—has re-emerged as a compelling theoretical response to intertwined crises of rapid urbanization, climate change, and land scarcity. Yet the concept, first articulated by Paolo Soleri in the 1960s, has remained largely unbuilt, constrained in part by the absence of transportation systems capable of supporting metropolitan-scale mobility within vertically stratified spatial structures. Conventional cable-driven elevators impose fundamental limitations in capacity, routing flexibility, and spatial efficiency, creating a critical bottleneck in the development of megastructural urban forms. This paper argues that emerging rope-free and magnetic-levitation (maglev) elevator systems constitute a transformative technological paradigm capable of overcoming these constraints. Drawing on interdisciplinary literature in urban theory, vertical transportation engineering, and smart infrastructure systems, the study develops a systems-level framework in which vertical mobility is reconceptualized as a continuous, multidirectional transit network analogous to an internal metro system. By synthesizing research on linear motor propulsion, multicar elevator operation, and magnetic levitation, the paper demonstrates how such systems can enable continuous circulation, dramatically increase passenger throughput, and significantly reduce the spatial footprint of transportation infrastructure within high-density environments. The analysis evaluates implications across spatial organization, energy performance, governance, and social equity, showing that integrating transportation infrastructure directly into the structural and functional logic of arcologies enables new forms of urban organization in which accessibility is governed by network connectivity rather than physical proximity. Critical challenges related to technological feasibility, lifecycle environmental impacts, economic viability, and the governance of algorithmically managed mobility systems are identified and discussed. By positioning transportation as the primary organizing framework of three-dimensional urbanism, this study contributes to bridging the significant gap between arcology theory and contemporary transportation engineering, establishing maglev elevator systems not merely as technological enhancements but as foundational infrastructure for a new paradigm of urban development.

Keywords: arcology; maglev elevator; vertical transportation; urban megastructure; linear motor propulsion; rope-free elevator; sustainable urbanism; three-dimensional urbanism

1. Introduction

The twenty-first century city faces a convergence of structural pressures that existing urban paradigms are ill-equipped to resolve. Rapid population growth—the United Nations projects that 68% of the world's population will reside in urban areas by 2050—intensifies demand for land, infrastructure, and housing at a pace that overwhelms conventional low-density urban expansion (United Nations Department of Economic and Social Affairs [UN DESA], 2018). Climate change simultaneously demands that cities reduce their carbon footprints, shrink impervious surface areas, and internalize ecological systems currently displaced by horizontal sprawl. The logic of three-dimensional urbanism—cities that grow upward rather than outward, integrating residential, commercial, civic, and ecological functions within compact megastructural envelopes—has therefore returned to prominence in both academic and professional discourse (Kurokawa, 1977; Picon, 2015).

The intellectual origins of this discourse lie primarily in the work of Paolo Soleri, the Italian-American architect who coined the term “arcology” in the 1960s—formalizing it in his 1969 monograph—to describe the fusion of architecture and ecology into self-sufficient, hypercompact urban environments. Soleri's project at Arcosanti in the Arizona desert remains the most sustained attempt to translate arcological theory into physical reality, yet its scale—a permanent community that has never exceeded approximately 100 residents against a design capacity of 5,000—falls dramatically short of the metropolitan ambitions embedded in his theoretical writing, making the gap between intent and realization unusually stark (Soleri, 1969; Wall, 1971). The gap between arcological theory and built practice has many causes, including financing, political will, and social acceptance, but one underappreciated bottleneck is infrastructural: the absence of transportation systems capable of serving metropolitan-scale populations distributed across the vertical dimension of a megastructure.

Conventional elevator systems, dominant since the installation of Elisha Otis's safety elevator in the Haughwout Building in New York in 1857, operate on a fundamentally limited paradigm: a single cable-suspended cabin moves along a single vertical shaft, serving passengers in batches determined by car capacity and call-scheduling algorithms (Al-Kodmany, 2018). Even in modern high-rise towers, elevator banks consume between 30% and 40% of total floor plate area in the most intensive configurations, and their capacity is bounded by the physical constraints of cable technology—maximum rope length, terminal velocity limits, and the impossibility of horizontal or diagonal travel within the same car-and-shaft system (Al-Kodmany, 2018). For a structure of arcological scale—defined here as a vertically integrated mixed-use environment housing a minimum population of 50,000 residents at densities exceeding 500 persons per hectare of net habitable floor area, with a vertical extent of at least 300 meters across differentiated functional zones—these constraints are disqualifying. An illustrative calculation shows why: a 50,000-resident structure at the densities of a New York or Hong Kong residential district would generate peak-hour elevator demand of approximately 15,000–20,000 person-trips per hour (assuming roughly 30–40% of residents making one trip during a 90-minute peak window). A conventional elevator car serving 15–20 persons per trip with a round-trip time of 3–5 minutes in a tall structure can handle roughly 200–400 person-trips per hour. Serving 15,000 peak-hour trips would therefore require on the order of 40–75 elevator shafts at minimum—before accounting for horizontal travel or the multi-zone routing that arcological mixed-use demands—consuming shaft cross-section area equivalent to a structurally significant fraction of usable floor plate at each served level. Such systems produce bottlenecks that would render the structure functionally

uninhabitable during peak demand periods, and they impose spatial costs that undermine the density efficiencies that make arcologies theoretically attractive in the first place.

This paper argues that the advent of rope-free and magnetic-levitation (maglev) elevator systems—technologies commercially prototyped by companies including thyssenkrupp’s MULTI system (subsequently developed under the TK Elevator brand following the 2020 corporate restructuring)—constitutes a paradigm shift with profound implications for arcological feasibility (thyssenkrupp, 2017). These systems, which use linear electric motor (LEM) propulsion rather than cables, enable multiple independent cabins to operate within a single shaft, travel horizontally as well as vertically, and be organized into loop-based continuous circulation networks structurally analogous to urban metro systems. This paper develops a systems-level theoretical framework connecting maglev elevator capabilities to arcological spatial organization, evaluates the multi-dimensional implications of that connection, and identifies the research, governance, and policy challenges that must be addressed before the framework can move from theory to application.

1.1 Research Questions and Scope

This paper addresses three primary research questions. First, what are the specific technical limitations of conventional elevator systems that constrain the development of arcological megastructures, and how do maglev elevator technologies address those limitations? Second, how does the reconceptualization of vertical mobility as a networked, multidirectional circulation system alter the spatial logic and organizational possibilities of three-dimensional urbanism? Third, what are the sustainability, governance, equity, and economic implications of integrating maglev-based mobility systems into arcological design?

The analysis draws on interdisciplinary literature spanning urban planning and design theory, vertical transportation engineering, smart infrastructure systems, energy performance research, and governance studies. It does not present primary empirical data but rather develops a synthetic theoretical framework grounded in existing technical literature, built precedents, and urban theory. The paper focuses primarily on high-density, purpose-built arcological structures rather than on the retrofitting of existing buildings, and it treats maglev elevator systems at the level of systems design rather than component-level engineering detail.

1.2 Paper Structure

Section 2 provides a theoretical and historical review of arcology as an urban concept, tracing its development from Soleri's foundational texts through contemporary applications and critiques. Section 3 examines the technical architecture of conventional and maglev elevator systems, identifying the parameters in which maglev systems represent a qualitative advance, and presents a comparative performance framework (Table 1). Section 4 develops the core theoretical framework, reconceptualizing vertical mobility as a transit network and analyzing implications for arcological spatial organization. Section 5 evaluates sustainability implications across carbon reduction, lifecycle assessment, and ecological integration. Section 6 addresses governance, equity, and economic dimensions. Section 7 identifies critical challenges and future research directions. Section 8 concludes.

2. Arcology: Theoretical Foundations and Contemporary Relevance

2.1 Soleri's Foundational Framework

Paolo Soleri's 1969 monograph *Arcology: The City in the Image of Man* established the conceptual architecture that continues to define arcological theory. Soleri's central argument was that the conventional horizontal city was a fundamentally entropic form: by distributing population and function across vast areas of land, it created enormous distances between interdependent activities, consumed vast quantities of energy for transportation, and imposed ecological destruction on an unprecedented scale. Against this, Soleri proposed the arcology as an "urban implosion"—a radical compression of urban functions into a three-dimensional structure of sufficient density to make the city itself function as a single complex organism (Soleri, 1969, p. 14).

The ecological argument was central to Soleri's vision. By concentrating population, the arcology would release surrounding land for agricultural and ecological recovery. Within the structure, the close proximity of functions would drastically reduce the energy costs of movement. The integration of passive solar design, food production, and waste recycling would minimize the structure's demand on external resources. Soleri explicitly framed arcology not merely as an architectural form but as a thermodynamic argument—a more efficient way of organizing the metabolic processes of urban life (Soleri, 1969; Pawley, 1971).

Transportation figured in Soleri's framework primarily as a problem to be eliminated rather than a system to be designed. The arcology's density was supposed to make most movement unnecessary: residents, workers, and civic facilities would all be within walking distance. Where mechanical movement was needed, Soleri envisioned it as peripheral and supplementary—freight systems, specialized transit for longer internal distances—rather than as the primary organizational logic of the structure. This framing underestimated the circulation demands of a structure housing populations equivalent to a mid-sized city; a point that critics of the megastructural tradition have noted, and which this paper takes as its central starting problem (Banham, 1976; Pawley, 1971).

2.2 Metabolism, Megastructure, and the Broader Context

Soleri's arcological theory emerged within a broader international discourse of megastructural urbanism that flourished in the 1960s and early 1970s. The Japanese Metabolist movement is particularly relevant to this paper's argument, as it explicitly theorized infrastructure as the primary organizing spine of megastructural form—a direct precursor to Section 4's reconceptualization of mobility as the organizational logic of three-dimensional urbanism. Kenzo Tange's 1960 Tokyo Bay plan, for example, proposed a linear megastructure in which a hierarchical circulation system—ranging from trunk highways to local pedestrian networks—determined the distribution of all other urban functions along its length. Kisho Kurokawa similarly argued that the metabolic cycle of urban systems, including transportation, should be made visible in architectural form rather than concealed within it (Kurokawa, 1977; Lin, 2010). British group Archigram and Yona Friedman's *Spatial City* proposed related large-scale structural concepts, each foregrounding mobility and adaptability as organizing principles (Friedman, 1975).

What these projects shared was a conviction that the city of the mid-twentieth century was inadequate to the demands of rapidly urbanizing, technologically accelerating societies, and that architectural form could be a vehicle for comprehensive social and ecological reorganization. They also shared, ultimately, the fate of remaining largely unbuilt. The oil crises of the 1970s, the political turn against large-scale planning, and the failure of several high-profile modernist housing projects contributed to a broader cultural rejection of megastructural ambition (Banham, 1976). Arcology, along with its intellectual relatives, retreated to the margins of architectural discourse.

2.3 Contemporary Revival and New Drivers

The past two decades have witnessed a renewed interest in arcological and megastructural thinking, driven by the intensification of the same urban pressures Soleri identified but at greater scale and urgency. Climate change has elevated the stakes of land consumption and carbon emissions in ways that make horizontal sprawl increasingly untenable as a long-term urban strategy (IPCC, 2022). Housing affordability crises in major metropolitan areas have renewed interest in density as a mechanism for increasing supply. Water scarcity, food security, and biodiversity loss have strengthened arguments for returning land to ecological and agricultural uses.

Several contemporary projects have tested elements of arcological thinking at various scales. The Bosco Verticale in Milan integrates substantial vegetation into high-rise residential towers—approximately 800 trees across planted terraces on two towers of 19 and 27 floors—demonstrating that significant ecological elements can be maintained within dense vertical residential structures, even if the project falls well short of the ecological integration envisioned by arcological theory (Boeri Studio, 2014). Singapore's approach to urban planning has consistently prioritized vertical density and integrated green infrastructure in ways that reflect arcological principles without adopting the megastructural form (Hee, 2017). Most dramatically, the NEOM project in Saudi Arabia—specifically its proposed component "The Line," a linear urban structure 170 kilometers long and 500 meters tall—has brought megastructural urbanism back into mainstream discourse, however contested its governance context and environmental claims may be—and however uncertain its long-term viability: by 2024–2025, reporting indicated that The Line had been drastically scaled back from its original 170-kilometer ambition to an initial phase of approximately 2.4 kilometers, with the broader project facing significant financial and logistical uncertainty (NEOM, 2022). The Line thus illustrates both the renewed cultural salience of megastructural thinking and the substantial gap between megastructural aspiration and realized development.

What remains underdeveloped in both the historical and contemporary arcological literature is a rigorous treatment of transportation as a systems-design problem. Soleri's framing of transportation as essentially unnecessary underestimates the mobility demands of complex urban economies. Contemporary megastructural proposals often describe transportation in aspirational terms—"high-speed transit," "autonomous mobility networks"—without specifying the technical systems that would make such visions operational. This paper identifies this gap as central and argues that addressing it requires engaging directly with the emerging generation of rope-free and maglev elevator technologies.

3. From Cable to Maglev: The Technical Evolution of Vertical Transportation

3.1 The Architecture and Limitations of Conventional Elevator Systems

The modern traction elevator operates on a straightforward mechanical principle: a cabin is suspended by steel cables (ropes) that pass over a sheave (pulley) driven by an electric motor, with a counterweight balancing the cabin load to minimize energy consumption. The system's elegance lies in its simplicity and reliability; its limitations are equally structural. First, rope systems impose a practical height ceiling. As shaft height increases, rope weight and elasticity become engineering constraints that raise cost and reduce efficiency. The practical ceiling for a single-rope system is approximately 500 meters, though supertall buildings extend effective reach by segmenting towers into independently served zones separated by sky lobbies—a technique employed in the Burj Khalifa, whose elevator shafts serve vertical segments of roughly 500 meters each (Al-Kodmany, 2018). Crucially, sky lobby segmentation does not eliminate the height constraint; it displaces it by imposing mandatory horizontal transfers that compound travel time and complicate journey routing within the structure.

Second, conventional elevators are confined to a single axis of movement. A cabin and its shaft define a dedicated vertical corridor; horizontal travel requires passengers to exit one elevator, traverse a corridor or lobby, and enter another. In a conventional office tower this limitation is manageable; in an arcological megastructure spanning multiple functional zones and potentially kilometers of height, it becomes a critical constraint on system performance. Third, the one-car-per-shaft architecture limits throughput. The capacity of a conventional elevator bank is determined by shaft count, car size, and scheduling algorithms—but no additional cars can be added to an existing shaft. In peak demand periods, conventional elevator banks routinely reach capacity and impose significant wait times (Barney & dos Santos, 1985). Double-deck elevators and sky lobbies have partially addressed this in supertall buildings, but they do not alter the fundamental one-car-per-shaft logic.

3.2 Linear Motor Propulsion: The Technical Foundation of Rope-Free Systems

The transition to rope-free elevator systems is enabled by a fundamental change in propulsion technology: the replacement of cable-and-sheave mechanics with linear electric motor (LEM) drives. In a conventional rotary motor, electromagnetic force produces rotational motion; in a linear motor, the same principles produce linear motion directly, without mechanical conversion. Linear motors are well established in magnetic levitation train systems, where they provide both propulsion and, in full maglev configurations, levitation (Boldea & Nasar, 1997; Laithwaite, 1975).

In the context of elevator systems, LEM propulsion offers three transformative capabilities. First, because no rope connects the cabin to a fixed point, there is no practical height limit; the cabin is driven entirely by electromagnetic interaction between its onboard motor components and the track embedded in the shaft wall. Second, because the propulsion system is distributed along the shaft rather than concentrated at a single motor-and-sheave point, multiple independent cabins can occupy a single shaft simultaneously, each driven by its own electromagnetic drive segment. Third, because the electromagnetic drive can be oriented in any direction—vertical, horizontal, or

diagonal—a shaft system designed around LEM propulsion can accommodate multidirectional travel within a single integrated network (thyssenkrupp, 2017).

The MULTI system developed by thyssenkrupp—first demonstrated in a dedicated test tower in Rottweil, Germany—represents the first commercial implementation of these principles. MULTI uses linear induction motors embedded in shaft walls to drive multiple independent cabins, and employs cable-free switching mechanisms at junction points to route cabins between vertical and horizontal shaft segments (thyssenkrupp, 2017). The system was designed with the explicit goal of applying metro-system principles to vertical transportation: continuous circulation, network routing, and high throughput without the capacity ceiling of traditional systems.

3.3 Magnetic Levitation: Full Contactless Operation

Beyond LEM propulsion, full magnetic levitation systems eliminate all mechanical contact between the cabin and the shaft structure, using electromagnetic forces to suspend the cabin as well as propel it. This approach, analogous to high-speed maglev rail systems such as Japan's SCMaglev, offers advantages in noise, vibration, maintenance requirements, and speed. Without mechanical contact, there are no friction-related wear components in the drive system, reducing maintenance costs and extending component lifespans. The absence of mechanical contact also enables higher speeds than conventional traction systems, which are limited by rope dynamics and cabin sway (Boldea & Nasar, 1997).

Research and development in maglev elevator systems has focused on two primary levitation technologies: electromagnetic suspension (EMS), which uses attractive forces between electromagnets on the cabin and ferromagnetic rails in the shaft, and electrodynamic suspension (EDS), which uses repulsive forces generated by superconducting magnets or permanent magnets interacting with conducting tracks. EMS systems are more mature technically and have been demonstrated in prototype elevator applications; EDS systems offer greater passive stability but require cryogenic cooling for superconducting implementations, adding system complexity (Boldea & Nasar, 1997). For arcological application, the most significant attributes of maglev elevator systems are their scalability, their multidirectional potential, and their operational performance characteristics—all of which are summarized in the comparative framework presented in Section 3.4.

3.4 Comparative Performance Framework

The case for maglev systems as arcological infrastructure rests on a set of comparative performance parameters across which they demonstrate substantial advantages over conventional systems. Table 1 presents a structured comparison across the dimensions most relevant to arcological application.

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Table 1. Comparative Performance Parameters: Conventional Traction vs. Rope-Free Maglev Elevator Systems

Parameter	Conventional Traction System	Rope-Free / Maglev System
Height ceiling	~500 m practical limit (rope weight, elasticity); extended via sky lobby segmentation at cost of transfer penalties	No practical height limit; propulsion fully distributed along shaft wall
Cabins per shaft	One (single car-and-shaft system)	Multiple independent cabins; continuous loop circulation
Travel direction	Vertical only; horizontal transfer requires separate systems	Vertical, horizontal, and diagonal within integrated network
Passenger throughput	Limited by car size and single-car headway	2–4× conventional capacity per equivalent shaft cross-section (thyssenkrupp, 2017; manufacturer estimate, independent validation pending)
Shaft area per capacity unit	High: counterweight, machine room, rope channel required	Lower: no counterweight or machine room; reduced cross-section per capacity unit
Energy regeneration	Counterweight-based partial regeneration	Regenerative braking on all descending segments; higher recovery rate
Parasitic energy demand	Low: counterweight passively balances load	Higher: continuous electromagnetic levitation power required; net balance context-dependent
Primary maintenance driver	Rope inspection, lubrication, periodic replacement	Power electronics, sensor systems, control software; suited to remote monitoring
Network topology	Linear (parallel vertical routes only)	Full network: loops, branches, express/local routes, transfer nodes

Note. Performance comparisons based on thyssenkrupp (2017), Al-Kodmany (2018), and Boldea and Nasar (1997).

Throughput is the most critical parameter. Studies of the MULTI system suggest that rope-free multicar shaft configurations can achieve two to four times the throughput of equivalent conventional elevator installations for the same shaft cross-sectional area, a product of simultaneous multi-cabin operation and the elimination of idle time at terminal floors (thyssenkrupp, 2017). It should be noted that this claim derives from manufacturer documentation rather than independent peer-reviewed evaluation. However, the underlying throughput logic is consistent with the established elevator traffic simulation literature: simulation-based studies of multi-car and destination dispatch configurations have consistently found that reducing inter-cabin

interference and eliminating terminal dwell time produces significant capacity gains relative to single-car systems operating under the same shaft cross-section (Barney & dos Santos, 1985; Siikonen, 1997). The manufacturer's specific multiplier should be treated as indicative rather than definitive pending independent empirical validation; the direction of the throughput advantage is well-supported. For a structure serving tens of thousands of residents, this multiplier has a direct effect on spatial programming: less area devoted to transportation infrastructure means more allocable to habitable space.

Energy performance presents a more nuanced picture. Maglev systems eliminate friction losses of cable-and-sheave mechanics and the parasitic mass of steel ropes, reducing gross energy input per passenger-trip. Regenerative braking on all descending cabin segments—recoverable at higher rates than counterweight-based systems—further improves the energy balance under high-load conditions (Almeida et al., 2012). However, EMS levitation systems impose continuous electromagnetic suspension energy demands with no equivalent in traction systems. Under conditions of sustained high loading—characteristic of the peak hours of a large residential arcology—the net energy balance likely favors maglev systems due to regenerative gains and reduced mechanical losses. Under low-loading conditions, the continuous levitation energy demand may shift the balance toward conventional systems. Optimizing net energy performance therefore requires careful management of cabin deployment patterns, levitation scheduling, and integration with building energy storage. This uncertainty does not negate the case for maglev systems in arcological applications—where sustained high loading is the design condition—but it underscores the importance of dynamic energy management as a design requirement rather than an afterthought.

4. Vertical Mobility as Transit Network: A Systems-Level Framework

4.1 From Elevator to Metro: The Conceptual Shift

The most significant contribution of maglev elevator technology to arcological theory is not technical but conceptual: it enables the reconceptualization of vertical transportation from a building service to a transit network. A building service model treats the elevator as a mechanical amenity—a means of moving individuals between floors in a building organized primarily around horizontal floor plates. The elevator serves the building's spatial logic but does not determine it. Travel time is measured in seconds, and the dominant design problem is minimizing wait times for individual users at individual floors.

A transit network model, by contrast, treats mobility infrastructure as the primary organizational logic of the spatial system. In a metro system, stations define the nodes around which urban activity clusters; the spacing, frequency, and routing of trains determine the effective geography of the city. Travel time is measured in minutes, and the dominant design problem is maximizing network connectivity—ensuring that any origin-destination pair can be reached within an acceptable time through a combination of direct service and transfers.

For a structure of arcological scale as defined in Section 1—a minimum of 50,000 residents across 300 or more meters of functionally differentiated vertical space—the transit network model is not merely preferable but necessary. The MULTI system's developers explicitly adopted metro-system analogies in their design rationale, describing the goal as achieving “the transport performance of an underground system within a building” (thyssenkrupp, 2017, p. 4). This paper extends that analogy to its logical conclusion: in an arcological context, maglev-based vertical mobility systems should be designed, governed, and spatially integrated using the principles and tools of transit planning rather than elevator engineering.

It is important to acknowledge a structural complexity this analogy introduces. In conventional urban transit systems, the network is designed to serve a pre-existing urban geography—nodes, activity centers, and population distributions that exist independently of the transit infrastructure. In an arcology, however, the spatial distribution of uses and the performance of the mobility network are designed simultaneously and are mutually constitutive: the network's effectiveness depends on where activities are located, and decisions about where to locate activities depend on assumptions about network performance. This circular design dependency does not invalidate the transit network framework, but it does mean that arcological spatial design and mobility network design cannot be treated as sequential problems. They must be solved iteratively and jointly, requiring a design methodology that integrates transit planning, land use programming, and structural engineering from the earliest stages of the design process rather than treating each as a separable phase. The transit-oriented development (TOD) literature offers a partial methodological precedent: Cervero and Kockelman (1997) demonstrated that land use density, diversity, and design must be co-optimized with transit network performance rather than planned sequentially, and subsequent TOD practice has developed iterative modeling frameworks in which ridership projections and land use allocations are refined together through multiple design rounds. Applied to arcological design, this co-optimization logic implies a parametric design methodology in which network topology, station locations, land use mix, and structural layout are treated as simultaneous variables subject to joint optimization across accessibility, energy, structural, and

equity criteria. Emerging computational tools in parametric urban modeling and agent-based simulation provide practical instruments for such iterative co-design, though their application to three-dimensional megastructural contexts remains an open research frontier (Batty, 2013).

4.2 Network Topology and Spatial Organization

The application of transit network principles to arcological vertical mobility begins with topology—the structure of nodes, links, and routes that define the network's connectivity. Conventional elevator systems have a degenerate topology: each shaft defines a single linear route, and the network is simply the union of parallel linear routes. There is no branching, no looping, and no possibility of multi-modal journeys within the vertical transportation system itself.

A maglev-based arcological mobility network can be designed with the full topological richness of an urban transit system. Loop configurations allow continuous cabin circulation, eliminating terminal floor dwell time and reducing effective headways. Branch configurations allow express routes serving specific functional zones alongside local routes serving all intermediate levels. Transfer nodes allow passengers to change routes within the network, enabling origin-to-destination journeys that combine multiple route segments analogous to transit transfers.

The spatial implications of this topological richness are significant. In a conventional high-rise, spatial organization is largely a product of horizontal floor plates: the floor is the primary unit of spatial organization, and vertical movement is a punctuation between horizontal domains. In an arcological structure organized around a maglev mobility network, spatial organization can be structured around transit nodes—clusters of activity concentrated at stations of the vertical mobility network, connected by active circulation corridors rather than passive floor plates. This produces a fundamentally different spatial grammar: a three-dimensional network of urban places connected by rapid vertical transit, rather than a stack of horizontal planes connected by intermittent vertical access.

4.3 Accessibility, Proximity, and Arcological Urban Geography

The reconceptualization of vertical mobility as a transit network has profound implications for the urban geography of the arcology. In conventional urban environments, accessibility is primarily a function of horizontal distance and travel time (Hansen, 1959). In a vertically organized arcology with a high-performance mobility network, this relationship is fundamentally altered.

If the maglev mobility network provides rapid, frequent, and reliable service between all major nodes—with headways comparable to high-frequency urban transit and travel times measured in minutes rather than hours—then effective distance between any two nodes is determined by network travel time, not physical separation in three-dimensional space. This decoupling of physical proximity and functional accessibility is one of the most significant theoretical contributions of the maglev mobility framework to arcological urban theory, and it has direct practical implications for land use organization within the structure.

If accessibility is governed by network connectivity rather than physical proximity, then the distribution of uses across the arcology can be optimized for criteria other than co-location. Noise-sensitive residential uses can be separated from heavy-activity commercial zones without sacrificing functional accessibility. Agricultural and ecological uses, which may have specific environmental requirements that place them at particular levels of the structure, need not be co-located with the human uses they serve; they can be distributed across the structure at levels

optimized for their environmental needs and connected via the transit network. This spatial flexibility is precisely what Soleri's walking-distance framework could not offer, and it is a direct consequence of the transit network reconceptualization enabled by maglev technology.

4.4 Integration with Building Structure and Systems

The spatial logic of the maglev mobility network must be integrated with the structural and mechanical systems of the arcological megastructure. In conventional high-rise construction, elevator shafts are structural elements—cores that carry vertical loads and provide lateral stability. The integration of maglev shaft systems must address both the structural function of the shaft core and the electromagnetic requirements of the propulsion and levitation systems. Electromagnetic interference between the maglev drive systems and the structural steel elements of the building is a potential concern, requiring careful shielding design; conversely, integrating linear motor track elements into the structural system of the shaft may offer efficiency opportunities analogous to the way post-tensioned concrete systems combine load-carrying and prestressing functions.

Fire safety and emergency evacuation present particularly acute integration challenges. Conventional elevator systems are not used for fire evacuation in most jurisdictions; stairwells and smoke-pressurized exit routes serve this function. In an arcological megastructure where vertical extent makes stairwell evacuation impractical for the majority of residents, the maglev mobility network may need to serve as a primary evacuation pathway—a role that imposes stringent reliability requirements and redundancy standards far beyond normal operational specifications. Fire-safe shaft compartmentalization, emergency power systems, and fail-safe cabin control in emergency conditions are areas requiring dedicated engineering research (Kuligowski, 2016).

5. Sustainability Implications: Carbon Reduction, Lifecycle Assessment, and Ecological Integration

5.1 Internalization of Urban Mobility and Carbon Reduction

The most significant sustainability argument for arcological urbanism—and specifically for maglev-enabled arcology—is not the direct energy performance of the elevator system but the indirect effect of internalizing urban mobility within a compact, electrically powered vertical transit network. The carbon emissions associated with surface transportation constitute a major component of urban carbon footprints globally. In the United States, transportation is the largest single source of greenhouse gas emissions, and in the most car-dependent metropolitan areas the share attributable to surface transportation can account for more than 40% of community-wide emissions (U.S. Environmental Protection Agency [U.S. EPA], 2023).

An arcological structure with a high-performance internal mobility network has the potential to dramatically reduce residents' reliance on surface transportation for daily activities. If residential, commercial, civic, and recreational uses are distributed across the structure and connected by the maglev network, the majority of daily trips can be served by the internal mobility system, which is electrically powered and can be supplied from renewable sources integrated into the structure. The elimination of automobile dependence for daily mobility is not merely a lifestyle choice but a structural outcome of the arcology's spatial organization, enabled by the performance characteristics of the maglev mobility network.

This argument must be qualified by the acknowledgment that arcological residents will not be entirely self-contained: connections to regional economic systems, supply chains, and social networks beyond the structure will continue to require surface or aerial transportation. The sustainability claim is thus comparative—reduced mobility-related emissions relative to equivalent conventional urban development—rather than absolute. Quantifying this reduction requires lifecycle assessment methodologies that account for both the construction and operational phases of the arcological structure, including the material and energy costs of maglev system installation (Crawford, 2011).

5.2 Lifecycle Environmental Assessment

Lifecycle assessment (LCA) of arcological megastructures presents methodological challenges that current LCA frameworks are not fully equipped to address. The embodied carbon of a structure of arcological scale is likely to be very large in absolute terms, even if modest on a per-resident basis compared to equivalent conventional urban development. The maglev mobility system contributes to this embodied carbon through the materials and manufacturing energy required for linear motor track elements, superconducting or permanent magnet components, power electronics, and control systems.

The payback period for this embodied carbon—the time required for operational carbon savings to compensate for the embodied carbon investment—is a critical metric for assessing genuine sustainability. Studies of conventional tall buildings have found embodied carbon payback periods of 10 to 50 years depending on structural system, location, and carbon intensity of the local grid, with taller and more material-intensive structures tending toward longer payback periods (Oldfield et al., 2009). Arcological megastructures, by virtue of their exceptional scale and the

novelty of their systems, are likely to occupy the longer end of this range, making the choice of structural system, material sourcing, and construction method critically important to the overall sustainability case.

Future research should develop arcology-specific LCA frameworks that account for the multi-decade operational periods over which such structures would generate sustainability benefits, the complex interactions between structural, mechanical, and ecological systems within the arcology, and the regional land use effects—including the release of land for ecological recovery—that represent among the most significant but most methodologically difficult sustainability benefits to quantify.

5.3 Ecological Integration and the Metabolic Arcology

Soleri's original vision of arcology was inherently metabolic: the structure was conceived as a system in which outputs from one subsystem became inputs to another, minimizing demand on external resources. Contemporary ecological design theory has developed this concept under the frameworks of industrial ecology, circular economy, and biomimicry, providing a richer theoretical toolkit for thinking about how arcological structures might genuinely function as metabolic wholes (Girardet, 2008; McDonough & Braungart, 2002).

The maglev mobility network contributes to the arcology's metabolic performance through its role in enabling the spatial distribution of subsystems across the structure. Waste treatment facilities, food production zones, energy generation arrays, and water management systems all have specific spatial and environmental requirements that may conflict with the requirements of habitable space. A high-performance mobility network allows these subsystems to be located at levels optimized for their functional requirements—south-facing food production terraces, basement-level waste treatment systems—without requiring co-location with the residential and commercial uses they serve. The mobility network becomes the metabolic connective tissue of the arcology, enabling functional integration across spatial separation.

6. Governance, Social Equity, and Economic Dimensions

6.1 Governing Algorithmic Mobility

A maglev-based arcological mobility network of the scale and complexity described here would necessarily be managed by sophisticated algorithmic systems. The scheduling, routing, and load balancing of hundreds or thousands of cabin movements per hour across a multi-dimensional network cannot be managed manually or by simple rule-based systems; it requires real-time optimization algorithms capable of responding to dynamic demand patterns, system anomalies, and emergency conditions (Siikonen, 1997). The governance of these algorithmic systems—who designs them, who controls them, and who has recourse when they fail—is a critical question that urban planners and policymakers have not yet adequately addressed in any context, and it becomes especially acute in the arcological case where the mobility system is more completely essential to daily life than any urban transit system yet built.

Algorithmic mobility management raises issues of transparency, accountability, and power that parallel those identified in the broader literature on algorithmic governance and smart urbanism. Kitchin (2014) has argued that the instrumentation of urban infrastructure with real-time sensing and algorithmic control creates new forms of urban intelligence that fundamentally alter the relationship between residents and the systems they depend on, concentrating technical power in ways that can be opaque to democratic accountability. Mattern (2017) similarly identifies the risk that the governance of algorithmically managed urban systems becomes insulated from public deliberation, operating according to optimization logics that are legible to engineers but not to the citizens affected by them.

In the specific domain of algorithmic transit management, the broader algorithmic governance literature raises concerns that optimization objectives embedded in routing algorithms may produce distributional effects across income and spatial lines that mirror and in some cases amplify existing patterns of inequality (Danaher et al., 2017; Pasquale, 2015). If the algorithm routing cabin movements prioritizes peak-hour commercial traffic, it may systematically disadvantage residential users during critical morning commute periods. If it optimizes for energy efficiency, it may concentrate service in high-demand zones and reduce service quality in less densely occupied areas. These distributional effects are political choices embedded in technical design decisions, and they require democratic oversight rather than purely technical management. The governance framework for an arcological mobility network should therefore include: transparent documentation of optimization objectives and constraints; independent auditing of algorithmic performance against equity and accessibility standards; a clear accountability structure for failures; and mechanisms for democratic revision of optimization objectives over time.

6.2 Social Equity and Access

The social equity dimensions of arcological urbanism have been a persistent concern in the critical literature. Critics of the megastructural tradition have argued that large-scale planned structures are inherently susceptible to social stratification—that their clearly differentiated levels and zones will reproduce and potentially intensify the class-based spatial segregation of conventional cities (Banham, 1976; Pawley, 1971). In the arcological context, transportation infrastructure is a primary vector through which social stratification can be materially expressed and perpetuated.

If access to the maglev mobility network is unequally distributed—if premium service is available only to residents of upper-level zones, or if service quality is systematically lower in lower-income residential areas—then the transportation system becomes a mechanism for reproducing and reinforcing social inequality within the structure. The history of urban transportation provides extensive evidence of how transportation investment decisions can systematically disadvantage low-income and minority communities (Bullard et al., 2004; Pucher & Renne, 2003). Designing the arcological mobility network as a genuine public good—with universal access, equal service quality across zones, and fare structures that do not exclude low-income residents—requires explicit commitment at the planning and governance level. Universal design principles should be built into the network design from the outset, not added as retrofits (Steinfeld & Maisel, 2012).

6.3 Economic Viability and Financing

The capital costs of rope-free and maglev elevator systems are substantially higher than equivalent conventional systems. The MULTI system commands a significant cost premium over conventional traction systems, as thyssenkrupp has acknowledged, justified in their analysis by lifecycle operational savings and throughput improvements (thyssenkrupp, 2017). At arcological scale, where the mobility network must serve populations equivalent to a medium-sized city, these capital costs are very large in absolute terms, even if manageable on a per-resident basis over a long operational period.

The financing structure for arcological development will significantly affect both economic viability and social equity outcomes. A developer-led model is likely to produce a structure optimized for high-income residents and premium commercial tenants—precisely the stratification outcomes that equity-focused critics of arcology fear. A public financing model may produce more equitable outcomes but faces political challenges in the current fiscal environment of most democratic governments. Hybrid models—public financing of infrastructure with private development of residential and commercial space within publicly owned structural envelopes—offer a potential path between these extremes and have precedents in transit-oriented development and large-scale public housing investment (Cervero, 1998). The density economics of arcological development are theoretically favorable, but they depend critically on achieving the population densities that make the system viable—an arcology that is half-occupied operates a full-scale mobility network at half its design throughput, dramatically worsening per-capita costs. Infrastructure investment must therefore be matched to actual occupancy, requiring flexible systems that can be expanded as occupancy grows rather than fully built out in advance of demand.

7. Critical Challenges and Future Research Directions

7.1 Technological Readiness and Scaling

Maglev elevator technology, while demonstrably feasible at the prototype scale, has not been deployed in full-scale operational buildings at anywhere near the complexity and scale required for arcological application. The MULTI system was developed by thyssenkrupp Elevator AG and first demonstrated in a dedicated test tower in Rottweil, Germany; following the sale of that division to private equity in 2020 and its rebranding as TK Elevator, commercial deployment of MULTI has remained limited to a small number of building projects, well short of the widespread adoption originally anticipated (thyssenkrupp, 2017). The gap between current technological readiness and arcological-scale deployment spans multiple dimensions: the number of simultaneously operating cabins (current prototypes operate tens; an arcological network might require hundreds or thousands), the network extent (current prototypes span hundreds of meters; an arcological network might span kilometers), and integration complexity (current prototypes are standalone transportation systems; an arcological network must be integrated with structural, energy, fire safety, and emergency management systems).

Bridging this gap requires a dedicated research and development program addressing scaling challenges across each dimension. Priority research areas include: multi-cabin conflict resolution algorithms for dense network operation; fault-tolerant network design that maintains service continuity in the event of individual cabin or shaft segment failures; fire-safe shaft design for maglev systems; and integration protocols for maglev mobility systems with building management, energy management, and emergency control systems. This research program requires collaboration between the vertical transportation industry, structural engineering, building systems engineering, urban planning, and fire safety engineering—a genuinely interdisciplinary undertaking that current research funding structures are not well organized to support.

7.2 Regulatory and Standards Frameworks

Existing elevator safety regulations in virtually every jurisdiction were developed for cable-based traction systems and do not adequately address the novel failure modes, safety requirements, and performance characteristics of rope-free and maglev systems. In the United States, the ASME A17.1 Safety Code for Elevators and Escalators requires significant revision to accommodate multi-cabin shaft systems, horizontal travel segments, and magnetically levitated cabins. Similar gaps exist in the European EN 81 standards and in the regulatory frameworks of most other jurisdictions (ASME, 2022). The regulatory development process must engage technical experts from the vertical transportation industry, fire safety and life safety engineering, structural engineering, and disability access advocacy, and it must be informed by operational experience from early commercial deployments of maglev systems. Without adequate standards, designers must negotiate individual variances with regulatory authorities for each project, adding cost, time, and uncertainty that discourages investment.

7.3 Social and Cultural Acceptance

Arcological urbanism as a social project faces challenges that go beyond technical and regulatory barriers. The proposition that large numbers of people should voluntarily choose to live

in dense, enclosed, vertically organized megastructures runs against cultural preferences—at least in North American and Northern European contexts—for low-density, individually controlled residential environments with direct access to the ground and natural landscape (Jacobs, 1961; Kunstler, 1993). Understanding the conditions under which people might find arcological living acceptable, and perhaps desirable, requires engagement with environmental psychology, housing preference research, and cultural studies that the existing arcological literature has not systematically undertaken.

The role of the mobility system in shaping residents' experience of the arcology is likely to be significant. In conventional apartment buildings, elevator wait times and crowding are among the most frequently cited sources of resident dissatisfaction (Gifford, 2007). In an arcological megastructure where the vertical mobility network is the primary means of access to nearly all daily activities, the quality of that network—its reliability, speed, comfort, and predictability—will be a primary determinant of residents' quality of life. A maglev network that delivers metro-quality service may make arcological living genuinely attractive; a network that performs poorly would make it genuinely unpleasant in ways that conventional urban residents can avoid by choosing different transportation modes.

7.4 Governance Innovation and Enabling Frameworks

Perhaps the most underappreciated challenge facing arcological development in democratic contexts is governance: the absence of institutional frameworks, legal categories, and political processes adequate to planning, financing, and managing structures of arcological scale and complexity. Arcologies span spatial extents that cross existing jurisdictional boundaries, impose infrastructure demands that exceed the capacity of individual municipalities, and require long-term planning horizons that exceed the electoral cycles of democratic governments. Existing land use law, building codes, and municipal finance structures were not designed for projects of this type.

Democratic societies have developed governance innovations for other types of large-scale, long-duration infrastructure projects—metropolitan planning organizations for regional transportation, special-purpose financing authorities for large infrastructure projects, public-private partnerships for mixed-use development—and these models provide partial templates for arcological governance. Special-purpose infrastructure authorities, analogous to those that have historically financed port facilities, transit systems, and large-scale housing projects, represent one institutional model through which the multi-jurisdictional and multi-decade requirements of arcological development could be managed within a democratic governance context. But the comprehensive integration of transportation, housing, commercial development, ecological management, and civic governance that an arcology requires goes beyond what any of these existing models fully addresses, and future research should explore the specific legislative and institutional innovations required to make arcological development feasible without recourse to the authoritarian governance shortcuts that have characterized the most visible contemporary megastructural proposals (NEOM, 2022).

8. Conclusion

This paper has argued that the emergence of rope-free and magnetic-levitation elevator systems represents a transformative technological development with profound implications for the feasibility and design of arcological megastructures. The argument rests on three interconnected claims. First, the specific technical limitations of conventional cable-based elevator systems—height constraints extended only at the cost of mandatory transfer penalties, single-axis movement, and one-car-per-shaft throughput limits—constitute a fundamental bottleneck that prevents conventional vertical transportation from serving the mobility demands of metropolitan-scale arcological populations. Second, maglev elevator systems overcome these limitations by enabling multi-cabin shaft operation, multidirectional travel, and continuous loop circulation, making possible throughput capacities and spatial efficiencies that bring arcological vertical transportation into a performance range comparable to surface urban transit. Third, this technological shift enables a conceptual shift: the reconceptualization of vertical mobility from a building service to a transit network, with profound implications for spatial organization, urban geography, energy performance, governance, and social equity within arcological structures.

The implications of this reconceptualization extend across every dimension of arcological design and governance. Spatially, a maglev mobility network allows the arcology to be organized around transit nodes rather than horizontal floor plates, enabling a three-dimensional urban grammar in which accessibility is governed by network connectivity rather than physical proximity. In terms of sustainability, the internalization of daily mobility within an electrically powered vertical transit network offers substantial potential for carbon emission reduction, while the metabolic role of the mobility network in connecting spatially distributed ecological subsystems contributes to the circular economy logic of the arcological structure. In terms of governance, the algorithmic management of a complex maglev mobility network raises critical questions about transparency, accountability, and democratic oversight that must be addressed through institutional innovation rather than technical design alone. In terms of social equity, the universal provision of high-quality vertical mobility is both a normative imperative and a practical precondition for the social diversity and economic vitality that distinguish genuinely urban environments from monocultural enclaves.

At the same time, this paper has been transparent about the challenges that stand between the theoretical framework it has developed and the practical realization of maglev-enabled arcological urbanism. Technological readiness gaps, regulatory framework deficiencies, social and cultural acceptance barriers, and governance innovation requirements all represent genuine and substantial obstacles that cannot be resolved by technological optimism alone. The paper's contribution is not to claim that these obstacles are easily overcome, but to establish that the conceptual framework—vertical mobility as transit network, transportation as the organizing logic of three-dimensional urbanism—is coherent, theoretically grounded, and worthy of the serious interdisciplinary research investment required to move it toward application.

The broader significance of this argument extends beyond arcology as a specific urban form. It contributes to a fundamental rethinking of the relationship between transportation infrastructure and urban spatial organization that has implications for the design of all high-density urban environments in the twenty-first century. As cities worldwide grapple with the intertwined imperatives of population growth, climate adaptation, housing affordability, and ecological sustainability, the question of how to organize human settlement in three dimensions will become increasingly central to urban planning and design. The answer this paper advances is compact,

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electrically powered, and organized not across the horizontal expanse of the metropolitan region but within the vertical density of the megastructure—cities not of sprawl, but of depth.

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