

RESEARCH ARTICLE

Contradiction and consistency: Deconstruction of landscape bridges based on multiple temporal-spatial scales



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Abstract This study explores the essential issues pertaining to a landscape bridge based on a multi-scale methodology, in view of the paucity of design theories for contemporary landscape bridges. We contribute to reinterpret landscape bridges on their physical temporal-spatial scales, instead of from perspectives of individual disciplines or their mechanical cooperation. Envisaged in a new systematized framework, we elaborate the dominant and their opposite counterparts of landscape bridges from a binary deconstruction point of view, i.e., (1) Development and retrogression on the temporal scale, (2) connection and separation on the spatial topographic scale, (3) skyphilia and topophilia on the spatial landscape scale, and (4) extroversion and introversion on the spatial architectural scale. The deconstructed multifaceted scales are instrumental in understanding landscape bridges from various perspectives, with a pyramid model proposed afterward to mediate the discovered oppositions and stimulate the cross-scale interactions. Various possible design paths could be derived from this well-organized and open-minded multiple system, which is initially expected in this study to inspire bridge designers with dissimilar backgrounds and calls for a wider ramification.

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1. Introduction

Architectural problems related to modern bridges have long been a gray field since the first iron bridge symbolizing the industrial revolution built in 1779. The gap between engineering and architecture always requires a continued remediation for their inconsistent development speeds and contents. Currently, in the field of bridge design, we are moving from a culture of one-dimensional evaluation to one that comprehensively evaluates bridges, including all the structural, architectural, and landscape aspects. We are confronted with a new situation that is different from any development period of bridges.

A seminal architectural study on bridges could date back to the third book of Andrea Palladio's *Architecture*, in which he addressed both architectural and technical aspects of wooden truss bridges and stone arch bridges (Palladio, 2002). It is a time that a craftsman could be quite capable of a dual role of contemporary architects and engineers. The separation of roles started from the foundation of the French National School of Bridges and Roads in 1747, and was thoroughly stimulated by the outbreak of the industrial revolution calling for specialized technologies. After that, pioneering bridge designers have paved the way for modern bridges with new materials and forms, the leading engineers among them include Thomas Telford (1757–1834), Robert Stephenson (1803–1859), Isambard Kingdom Brunel (1806–1859), John A. Roebling (1806–1869), Gustave Eiffel (1832–1923), Gustav Lindenthal (1850–1935), Robert Maillart (1872–1940), Othmar Amman (1879–1966), Eugène Freyssinet (1879–1962), David B. Steinman (1886–1960) and Christian Menn (1927–2018) (Billington, 1985). By operating on mega-structures that focus on function and efficiency, they opened up the possibility for bridge engineering to be structural art, which is prior and now to a certain extent parallel to modernist architecture. Some early bridge engineers have a direct influence on the formation of Modernism, such as Gustave Eiffel and Robert Maillart.

Along with its astounding structural development for longer span and higher efficiency, the aesthetic aspect of bridges was also sensitively evaluated by some prestigious bridge engineers and scholars. Mock and Kassler (1950) were probably the first to address the aesthetic philosophy of modern bridges in the perspective of modernism, such as form following function, exposure of structure, and elimination of detail. The German engineer Leonhardt (1968, 1984) devoted all his life to the aesthetic design of bridge structures by developing tentative design rules for good bridge forms, such as good order and proportion, simplicity and pureness, serviceability and suitability, easy fabrication or construction, and creativity and intuition. He constructed an aesthetics-involved design procedure for the structural concept design of modern bridges, which was widely accepted by bridge engineers worldwide in the 20th century. In relation to the new forms and styles of modern bridges (Billington, 1985; Billington and Gottemoeller, 2000) was an indispensable scholar to clarify the structural history of modern bridges, specifically from the late 18th century to the 1980s. In retrospect, he provided an evolutionary description of the main modern bridge types:

the steel arch bridge, the suspension bridge, the pre-stressed concrete bridge, and the cable-stayed bridge in order. Billington was a protagonist of structural art, which in his opinion, was an art form parallel to but independent of architecture. In his clear distinction of engineers, architects and sculptors, these roles predominately act in different spheres, and the structural art basically originates from the shape and size of a bridge, which dominate its appearance, but not the details, color, or surfaces. Gottemoeller, another important engineer and scholar, proposed the concept of "bridgescape" (Gottemoeller, 1998), and placed great emphasis on the environmental impact of bridge aesthetics by breaking down the bridge design into its most fundamental elements—line, form, placement in the site, color, texture, and ornamentation. Furthermore, in the end of the last century, two mature compositions epitomizing engineers' wisdom of bridge aesthetics were published to provide design guidelines for different bridge types, components, and facilities, each of which could contribute to bridge aesthetics when sensitively considered (National Research Council US. *Transportation Research Board*, 1991; Office of Bridges and Structures, 1995).

Discussed thoroughly by engineers, the structural aesthetics innovation quickly became a dead-lock for its exclusive focus on the integral design in a higher level, and the pervasive analysis software further weakened the original structural design in a way of emphasizing calculation. Regardless of its dimension and site, a bridge designed by an engineer was probably an intensification of what already existed on the basis of bridge typology. The isolated creative cases could only happen with very few gifted engineers such as Jürg Conzett, who was adept at organizing the structure and space of pedestrian bridges located in the mountains (Conzett and Mostafavi, 2006). This situation changed from the return of architects in the field of bridge design at the end of the 20th century. The Alamillo Bridge and Zubizuri Bridge (Jodidio, 2019) by Calatrava reinterpreted the fascination of structural balance by visually breaking the symmetry and architecturally organizing the order of components in a tectonic way. The Sheikh Zayed Bridge (Bellini et al., 2008), Zaragoza Bridge Pavilion (Monclús, 2009), and Danjiang Bridge (Spallone, 2017) by Zaha Hadid were excellent applications of the pervasive parametric design characterized by shape with smooth curvature variation. Architectural penetrations were also applied in other influential bridge designs led by architects to improve their shape and space, such as the Millennium Bridge (Dallard, 2001) and Millau Viaduct (Shannon and Smets, 2010) by Foster and Partners, the Miho Museum Bridge by Leoh Ming Pei (Watanabe, 2002), the BP Pedestrian Bridge by Frank Gehry (Iyengar, 2006), the Simone de Beauvoir Footbridge (Architects and Feichtinger, 2008) and Butterfly Bridge (Morgen, 2017) by Dietmar Feichtinger Architects, the Kurilpa Bridge (Beck and Cooper, 2012) and Helix Bridge (Ting et al., 2014) by Cox Architecture, and the Merchant Square Footbridge (Knight, 2014) and St. Philips Footbridge (Beade-Pereda, 2019) by Knight Architects.

Another wave motivating the bridge concept design is to regard the bridge as a landscape architecture from a broader landscape view. In a higher system level, landscape has been found more relevant with sites in which a strictly

architectural order of the city has been rendered obsolete or inadequate through social, technological, or environmental change (Waldheim, 2016). Landscape provides new possibilities based on focusing on site-dependent characters and systematic requirements, rather than a strictly architectonic or structural mode for place making through decentration. Typical cases adopting a landscape strategy include the Arganzuela Helix Footbridge by Dominique Perrault Architecture (Castañón, 2014), the Dafne Schippers Bicycle Bridge by NEXT Architects (Becker et al., 2018), and a series of footbridges designed by Turenscape in recent years (Hermaputi, 2017; Özçakı, 2017; Yu et al., 2018), all of which have a visual, functional, ecological, and experiential interaction with their surroundings.

Due to the multifaceted aspects of bridges, we herein define a landscape bridge from two aspects. Namely, in a positive way, a landscape bridge calls for special aesthetic strategies to motivate the landscape it dwells in, and itself is an active landscape element in the environment. In a passive way, a landscape bridge refers to the one that requires careful aesthetic considerations; otherwise, its construction may have an adverse influence on the original landscape. However, in achieving the goals of a landscape bridge, there are quite a lot of controversies from bridge designers with various backgrounds. This interdisciplinary field requires an immediate injection of renewing theories under the actual intricate situation, which could be reflected in the following aspects:

(1) **Criteria Coordination.** The design philosophy adopted by different designers emphasizes different aspects of the bridge design. In many cases, the economy and construction of a landscape bridge should make a sacrifice to realize an environmentally effective goal, which often arouses dissatisfaction from the conservative and experienced engineers, and further destroys both the enthusiasm of architects and the possibility of a creative landmark. On the other hand, irrational proposals emphasizing radical novelty could also lead to inefficiency of the infrastructure, which is ill-matched with the investment. A design criteria coordination of various goals is required for all designers regardless of their roles.

(2) **Scale Differentiation.** Most bridges designed by architects are with small or medium spans. Although architects have demonstrated their capacity at this length scale, few of them could take the role of leading in large-scale bridge design except for the work of reshaping. Similarly, only few creative engineers could present a systematic approach beyond the classic structural art, while operating on small or medium bridges. A comprehensive capacity unrestricted by scales could probably be achieved by a multi-scale thinking, which will help both engineers and architects to overcome their weaknesses.

(3) **Cooperation Mechanism.** Although a general consensus for cooperation has been achieved among engineers and architects to reach the ideal of landscape bridges, one of them will inevitably occupy the dominant role in the design process. If not properly coordinated, the outcome would probably turn out to be a mechanical mixture, a landscape addition to a rigid structure, or a structural compromise to the irrational conception. A gap in the execution of cooperation is far more overlooked when we traditionally place great emphasis on the relationship between the roles of engineers and architects.

(4) **Common Theory.** As the preliminary investigation above, most concept design theories of bridges were concluded by engineers or scholars with an engineering background. Nevertheless, thoughtful engineers are relatively infrequent from the new century when most of them are involved in computer-aided structural analysis. In addition, few architects have given fruitful perspectives for the bridge design comparing to their insight into architecture and landscape, which could be attributed to their limited energy and practice. Currently, the design theory for landscape bridges needs a prompt refinement to offer a common base for the various roles of contemporary bridge designers, not just case studies.

Encountered with the mentioned problems originating from separate disciplines and their cooperating procedure, the design of landscape bridges requires a new and systematic inspection instead of the traditional emphasis on structural components, aesthetic styles, and vague cooperation of various disciplines. Envisaged in this perspective, this study will demonstrate the multifaceted aspects of landscape bridges from time to space and from large to small spatial scales on a systematic level. The incorporation of multiple scales into landscape and particularly its multidisciplinary roots are considered as fundamental advances in supporting the sustainable development of social-ecological systems (Khoroshev, 2020). To achieve this higher systematic goal, a new framework including multiple scales for landscape bridge design, will first be established. Thereafter, a deconstruction work is conducted specifically on the basis of the deconstruction theory to find the binary oppositions of different temporal-spatial scales, with their dominant aspects and the opposite demonstrated in an unprecedented way. The four multifaceted scales are further elaborated to offer the factual basis and theoretical support for landscape bridge design. Meanwhile, consistency strategies are investigated to mediate the binary oppositions of the illustrated scales, which may open minds for various bridge designers and promote their cooperation.

2. Multi-scale systematic theory and methodology

A multiple paradigm is used to address the complexity and multidisciplinary nature of environmental problems, the spatial and cultural de-localisation of co-operating research groups, and the recognition of cross-scale effects with different phenomena operating at different scales (Villa, 2001). The multi-scale system proposed for landscape bridge design is to establish a new effective framework based on the evolution of its design metrics, to reconcile the various disciplines and design roles, and to inspire creative landscape bridge designs by using a systematic theory and methodology. The multi-scale system could be achieved by obeying the following route:

(1) **System construction.** The new multi-scale system is expected to formalize and illustrate the complexity of a bridge in its natural environment, it will differ from the design metric based on structural typology to pursue a single aim of structural art, or the design mode motivated by the collaborative disciplines contributing to an organic combination. Three spatial scales in conjunction with its

evolutionary history are constitutive of this new systematic framework (Fig. 1), i.e. the spatial topographic scale, the spatial landscape scale, the spatial architectural scale, and the temporal scale. Although constructed on the basis of the contributions of relevant disciplines, the new framework will not emphasize their difference and relationship as the literal meaning of the proposed scales, which is more about the spatial and temporal hierarchy. All disciplinary issues could be included in this multi-scale system, and its primary goal is to sort out a well-organized and comprehensive framework that covers the most central aspects with respect to a landscape bridge design.

(2) **Scale deconstruction.** The constitutive scales will be deconstructed within the structuralized system. According to the deconstruction theory, the traditional binary oppositions are never equivalent, and they are always hierarchically ranked, which means that one pole is privileged at the expense of the second (Guillemette, 2006). To reveal the invisible pole behind the privileged one, the first step is to thoroughly point out the dominant thinking way we generally perform on every scale. In reverse, their opposite aspects that have not been realized in the past could be discovered, which potentially affect the landscape bridge design. The dualism-based deconstruction work will be shown in Section 3.

(3) **Scale representation.** Characteristics of the deconstructed oppositions will be meticulously investigated on the basis of theoretical and practical evidence, in order to distinguish the differences between the binary oppositions. Subsequently, new possibilities of reversing and neutralizing the dominant and its opposite will be studied to provide a new understanding of the landscape bridge design on multiple scales. Both the qualitative and quantitative methods are adopted by literature survey and data acquisition to offer sufficient and convincing evidence for the scale representation of landscape bridges, which could be seen in Section 4.

(4) **System integration.** The ultimate goal of deconstruction is to mediate the ambivalent oppositions within the observed scope. Neither part of the binary opposition can exist without the other because they are actually interwoven, which is also the same for different scales. The new multi-scale systematic theory and methodology could only be applicable when the consistency of oppositions and the coordination of different scales are achieved. An integrative strategy will be generated based on the interaction of oppositions and scales in Section 5 to see what possibilities the proposed system may open up.

3. Scale deconstruction of landscape bridges

Deconstruction, proposed by the French philosopher Jacques Derrida to address the relationship between text and meaning of linguistics, has inspired a range of theoretical revolutions in various fields such as architecture. The main idea of deconstruction could be easily understood from the following aspects. First, deconstruction is of considerable philosophical importance to provide an alternative to the “metaphysics of presence” rooted in classic western philosophy (Sweetman, 1997). This notion means that deconstruction draws on something that may have been overlooked, ignored, and even

suppressed outside the ontology, thus offering a new view to understand the meaning of everything. Second, deconstruction is a development of structuralism, which, to a great extent, resorts to the binary oppositions constituting a structure, such as pairings of signifier/signified and synchronic/diachronic (Derrida, 2016). Generally, one of the two opposites assumes a role of dominance over the other, such as good over bad, speech over the written word, and male over female. Third, deconstruction, as the representative of what is called post-structuralism, advocates the dismantling of logocentrism or the violent hierarchy of structuralism. According to Derrida, the classical philosophical oppositions do not deal with the peaceful coexistence of a vis-à-vis, which means the dominant in a pair always governs its subservient counterpart. The core ideology of deconstruction is to find, overturn, and establish these oppositions by marking their difference and eternal interplay, and it is necessary for an interminable analysis: the hierarchy of dual oppositions always reestablishes itself (Derrida, 1972).

The deconstruction strategy of landscape bridges could then be formulated on the basis of the understanding of Derrida’s theory: to structuralize the observed scales with binary oppositions, discover and differentiate the dominant and subordinate sides of these oppositions, and stimulate their interplay by reorganizing their positions. In practice, the primary task of deconstruction of landscape bridges is to construct the binary oppositions by exploring their dominant and undervalued aspects on the observed scales (temporal scale, spatial topographical scale, spatial landscape scale, and spatial architectural scale).

Generally speaking, on a temporal scale, the bridge is the outcome of technological development. On a spatial topographical scale, it connects what is separate in topography. On a spatial landscape scale, it serves as a picturesque element in its landscape background. Moreover, the bridge itself deserves an elegant appearance on a spatial architectural scale.

These statements are in obvious conformity with what we are envisioning when we talk about landscape bridges. Thus, a dualistic structure of every observed scale could be constructed accordingly by inverting the seemingly irrefutable descriptions:

(1) **On the temporal scale:** whereas the development of structural technology has made a significant contribution to modern bridge engineering and become an indispensable part of it, the other aspects of bridges concerning their culture, regionalism, and recreation etc., may inevitably retrogress in this technology-led process.

(2) **On the spatial topographic scale:** A bridge could not only connect the separate topography as it is supposed to be, but also separate what should otherwise be connected when not scrutinized.

(3) **On the spatial landscape scale:** Apart from contributing to a picturesque landscape view as a geographic landmark, a bridge could also be organically woven into the landscape and distract our attention from eye to body, from above-ground to on-ground, and from transcendence to attachment. Interpreted as skyphilia and topophilia, these two different forms will work as binary oppositions within the landscape scale to be discussed.

(4) **On the spatial architectural scale:** A landscape bridge is supposed to own a stunning appearance from both

a global and local space view. In most cases, a landscape bridge is an extroverted consideration that dominates the architectural expression. An introverted strategy with respect to the on-bridge issues is seldom implemented in priority when conceiving the architectural form of a bridge. Even though it is being stereotyped in architectural theories, the extroversion-introversion dichotomy is a barely explored jungle for the architectural space of bridges.

A clearly deconstructed structure on the multiple scales of landscape bridges is shown in Fig. 2, with the dominant and the generally neglected opposite sites discovered.

4. Scale representation of landscape bridges

4.1. Temporal scale — development and retrogression

The formidable development of modern bridges may date back to the end of the 18th century, having made its ongoing progress over 200 years. Despite the early modernist architects who drew inspiration from bridge engineering, few contemporary architects and even engineers can adequately know the history of bridge technology. An effective way to make both of them informed of the most fundamental evolution is to survey the span development history of the typical modern bridge types for a holistic understanding, and the situation of their current development phase could be speculated in conjunction with an overall periodization analysis.

Based on Billington's extraordinary investigation of modern bridge history ranging from the 1870s to the early 1980s (Billington, 1985), and the data acquired from Wikipedia, the span capacity evolution of four typical modern bridge types could be presented, which is concurrently shown in Fig. 3. The three pragmatic structural types are used to roughly categorize the modern bridges on the basis of their mechanical traits, namely, the beam/cantilever bridge (bending moment dominant), the arch bridge (arch pressure dominant), and the cable bridge (cable tension dominant), including the common truss form because it could be applied in all of the three types. In particular, unequal spanning capacities have been discovered with the suspension bridge and the cable-stayed bridge, both classified as cable bridges. Thus, the four observed modern

bridge types herein are the cantilever bridge, the arch bridge, the suspension bridge, and the cable-stayed bridge.

In Fig. 3, the span capacities of observed bridge types have followed an incremental development since the 1800s, except the cantilever bridge which has been capable of spanning a length over 500 m in the end of 19th century, namely, the extraordinary Forth Bridge with two main spans of 521 m completed in 1890, remaining the second longest cantilever bridge nowadays. The technology of the cantilever bridge has been mature and stable since the 1900s. Instead of pursuing longer spans, the development of cantilever bridge is more about structural and material improvement, and currently, it is sufficient to support any spanning schedule under 500 m. Although lagging behind the cantilever bridge, the developments of the other three bridge types have a relatively trackable timeline, and their drastic and stationary development periods could be clearly discerned by investigating their longest main span records. Specifically, the arch bridge reached its first main span record over 500 m in the 1930s and stepped into a period of steady development since then. Now, the longest arch span recorded is the Chaotianmen Bridge, with the main span of 552 m built in 2009. With regard to the suspension bridge, two obvious leaps took place in the 1930s and 1990s, of which the representative works are the Golden Gate Bridge (main span of 1280 m and completed in 1937) and the Akashi-Kaikyo Bridge (main span of 1991 m and completed in 1998) respectively. The latter holds a record of the longest bridge up to date, which also indicates a relatively steady development phase of the suspension bridge. As regards the cable-stayed bridge that started to unleash its spanning potential from the next half of the 20th century, a rapid technology promotion since the 1990s, achieved a competitive length of the main span over 1000 m in the Sutong Yangtze River Bridge (main span of 1088 m and completed in 2008) and the Russky Bridge (main span 1104 m and completed in 2012). And it probably has reached the capacity limit in the short run.

To further comprehend the historical progress of bridges, a periodization analysis is conducted to elaborate its regularity and trait (Table 1). Two types of periods are defined, namely, the period during which structural technology of bridges is always given a more privileged position than its artistry aspects, and the period during which technology and art could equilibrate in a way that neither

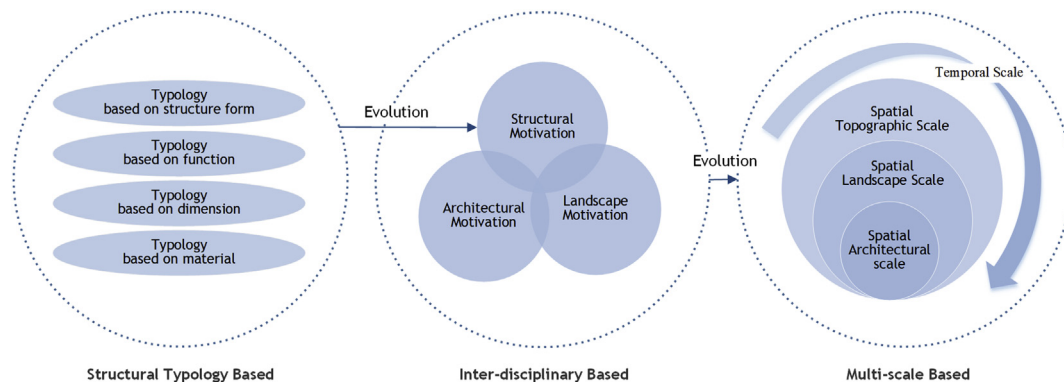


Fig. 1 Frameworks used for landscape bridge design.

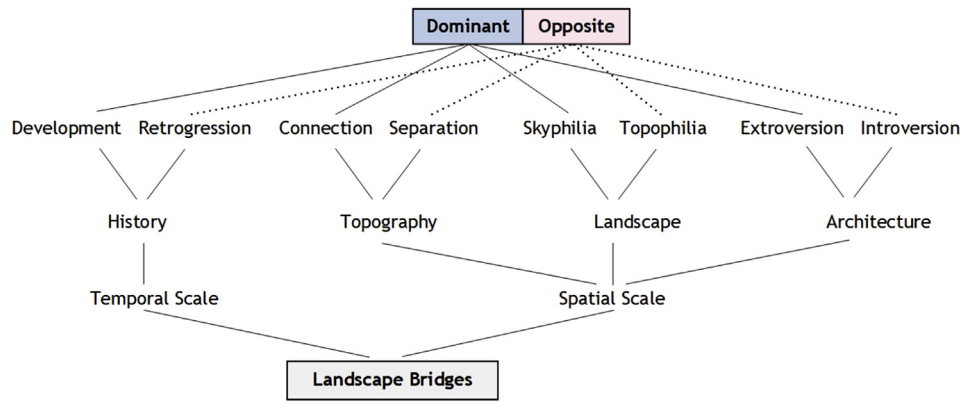


Fig. 2 Deconstruction of a landscape bridge.

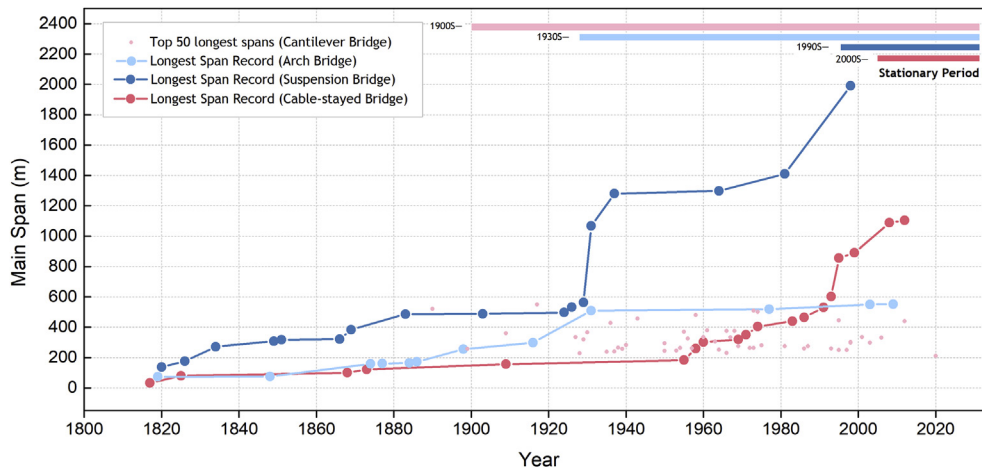


Fig. 3 Span development of the main modern bridge types.

of them is overwhelming. Generally, the first one refers to the period a technology boom was accelerated by the emergence of new materials, innovative forms, and construction improvements. In this period, the most fundamental structural issues require an immediate solution, and few opportunities for aesthetic creation could be offered, except what is formed as structural art in this process. Subsequently, the second defined equilibrium period often appears after the slowdown of an enormous technological development, and it does not mean that the structural development has stagnated in this period. In a relative sense, it is proceeding in a gradual and cumulative way, leaving sufficient space and time for other fields to digest the technological achievements and make non-structure-driven innovations on the founded technological strength.

In Table 1, to circumscribe the two defined periods, some representative bridges within the two periods and the epoch-making bridges that may serve as links between them are carefully selected. The materials and the four bridge types mentioned above are used to evaluate the characteristics of the proposed periodization. The divided phases could be understood by the following elaboration:

I/a (before around the 1st century BC)

This period mainly refers to the time before the ancient Roman aqueducts, which symbolized the achievement of stone arch bridges, became technically mature. It is a time when bridges were mainly made of wood and stone with primitive forms of beams and arches to find the technological solution for simple spanning.

I/b (around the 1st century BC–1770S)

The maturity of the ancient Roman aqueducts opened up a period in which the stone arch bridges prevailed in the next more than 1000 years. As a herein defined milestone, the key technologies of the ancient Roman aqueducts have been introduced by the Roman architect Vitruvius in his work *De architectura* in the 1st century BC. Thereafter, cities and towns throughout the Roman Empire emulated and refined this model, which could indicate the beginning of an equilibrium era considering both technology and artistry. The best evidence afterward is the graceful stone arch bridges built in the renaissance. Meanwhile, a similar period could be found with wooden bridges in Asian countries, typically the woven timber arch bridges (Zhou et al., 2018).

Table 1 Periodization of bridge development.

Sequence Number	Phase Characteristics	Time Periods	Representatives(•) and Milestones(★)	Description							
				Material				Bridge Type			
				W	S	S _t	C	A	B	S	C
I/a	Technology	Around the 1st century BC	• Pontoons, Cany bridges • Stone arch bridges • Wood cantilever bridges	⤴	⤴			⤴	⤴		
	Atistry		★ Ancient Roman Aqueducts		○			○			
I/b	Equilibrium	Around the 1st century BC-1770S	• European stone arch bridges • China's woven timber arch bridges	⤴	⤴			⤴	⤴		
			★ Ironbridge Gorge			○		○			
II/a	Technology	1770S-1930S	• Menai Bridge • Brooklyn Bridge • George Washington Bridge • Forth Bridge • Garabit viaduct • Eads Bridge • Bayonne Bridge • Tavanasa Bridge • Schwandbach Bridge			⤴	⤴	⤴	⤴	⤴	
	Atistry		★ Golden Gate Bridge ★ Salginatobel Bridge			○				○	
II/b	Equilibrium	1930S-1980S	• Luzancy Bridge • Fehmarn Sound Bridge • Reichenau Bridge • Verrazzano-Narrows Bridge • Severin Bridge			⤴	⤴	⤴	⤴	⤴	⤴
			★ Ganter bridge				○				○
III/a	Technology	1980S-2000S	• Humber Bridge • Tatara Bridge • Alamillo Bridge • Zubizuri Bridge			⤴	⤴	⤴	⤴	⤴	⤴
	Atistry		★ Akashi-Kaikyo Bridge			○				○	
III/b	Equilibrium	2000S-now	• Russky Bridge • Chaotianmen Yangtze River Bridge • New San Francisco-Oakland Bay Bridge • Danjiang Bridge			⤴	⤴	⤴	⤴	⤴	⤴

Note: W, S, S_t, and C represent wood, stone, steel, and concrete, respectively;

A, B, S, and C represent the arch bridge, the beam bridge, the suspension bridge and the cable-stayed bridge, respectively;

⤴ indicates a drastic development period, while ⤴ means a relatively steady development period;

○ shows the associated characteristics of the bridges marked as milestones.

II/a (1770S–1930S)

This era is a period catalyzed by the Industrial Revolution taking the iron bridge as a symbol (Cossons, 2002). It directly led a way to modern bridges characterized by iron, steel, and concrete material, benefiting from the striking technological development of materials, fabrication, and construction. New forms in conjunction with new materials were contrived to span the never conquered distance and topography, namely, (1) the iron or steel suspension bridge, including the noticeable Menai Bridge (Paxton, 1977), the Brooklyn Bridge (McCullough, 2012), and the George Washington Bridge (Rockland, 2020); (2) the steel cantilever bridge, most prominent of which is the Forth Bridge

(Baker, 1884); (3) the iron and steel arch bridge, the typical examples should cover the Garabit viaduct (Simondon, 2012), the Eads Bridge (Kouwenhoven, 1982), and the Bayonne Bridge (Thrall and Billington, 2008); (4) the concrete arch bridge, mainly facilitated by Robert Maillart, including his masterworks, such as the Tavanasa Bridge and the Schwandbach Bridge (Billington, 1989). The peak of this prosperous development period could be marked by the Golden Gate Bridge (MacDonald and Nadel, 2013) and the Salginatobel Bridge (Billington, 1989), representing the outstanding achievements of the new materials, namely, the steel in the form of the suspension bridge and the concrete in form of the arch bridge, respectively.

II/b (1930S–1980S)

Following a stunning development phase lasting for approximately 150 years, bridge technology constrained by new engineering problems began to slow down its pace. The specific technological issues with concern in this period mainly include: (1) the wind-resistance problems of the long-span suspension bridge, originally aroused by the collapse of the Tacoma Narrows Bridge in 1940 (Olson et al., 2015), (2) the requirements for steel with higher performance, (3) the prestress technology to improve the concrete bridge, and (4) the development of the new modern bridge type, namely, the cable-stayed bridge. As shown in Fig. 3, no noticeable span improvements have been made during this relatively pragmatic period preparing technology storage for the next breakthrough and focusing on the improvement of bridges with medium and small spans. The representative bridges worth mentioning are the Luzancy Bridge, a prestressed concrete bridge designed by Eugène Freyssinet (Shushkewich, 2013); the Fehmarn Sound Bridge, a network arch bridge opening up the aesthetic possibilities for steel arch bridges (Tveit, 2008); the Reichenau Bridge by Christian Menn, considered as a successor of Maillart's concrete bridges (Pipinato, 2015); the Verrazzano-Narrows Bridge, a more modern suspension bridge slightly breaking the length record of the Golden Gate Bridge in 1964 (Brumer, 1966); and the Severin Bridge, a symbol of the early cable-stayed bridges in development (Walther, 1996).

III/a (1980S–2000S)

The new period characterized by another technology breakthrough may have started from the notable Ganter bridge by Christian Menn, which not only held aesthetic quality in the highest regard but also represented a combination of prestress technology and the prevailing cable-stayed bridge form (Rossiter, 2008). Although being fairly short in history, this subdivided period deserves particular attention of current research. Besides shaping up all the major modern bridge forms, two significant leaps have been made to explore the spanning capacity limit of the suspension bridge and the cable-stayed bridge respectively. For the former, it is approximately 2000 m, which could be demonstrated by the Humber Bridge (Fisher, 1982) and the Akashi-Kaikyo Bridge (Matsumoto and Yasuda, 1990), breaking the length record of the Verrazzano-Narrows Bridge in succession. For the latter, it is approximately 1000 m, which could be observed from the Tatara Bridge completed in 1999 (Ito and Endo, 1994). In addition, the bridge typology founded by engineers encountered an immediate challenge when architects represented by Calatrava stepped into this field, applying asymmetric structural forms in bridges, such as the Alamillo Bridge and the Zubizuri Bridge (Jodidio, 2018). Together with the other architectural and landscape involvement, the structural innovation of bridges, especially with medium and small spans, was tremendously stimulated in reverse, thus opening up the time what we called landscape bridges. We began to consider bridges in a trans-disciplinary view instead of the excessive pursuit for structural achievements, and this was totally on the basis of the development and awareness of all associated disciplines.

III/b (2000S–Now)

The Akashi-Kaikyo Bridge with a main span of 1991 m completed in 1998 could be marked as the highest achievement of bridge technology to date, having kept its span length record for over 20 years. Although bridge engineers are still making efforts to challenge the span limit of various bridge types in the new century, e.g., the Russky Bridge (Pipinato, 2016), the longest cable-stayed bridge with a span of 1104 m completed in 2012, and the Chaotianmen Yangtze River Bridge, the longest arch bridge with a span of 552 m completed in 2009 (Xiang et al., 2010), all the modern bridge types are following a gradual development route, and a drastic breakthrough is unlikely to take place in the near future. Moreover, the focus on bridges has been drawn from the challenge of structural limit to a more diverse and interacted cooperation, gathering all relevant disciplines to contribute to the period definitely for the emergence of more outstanding landscape bridges. Typical examples in this period include the New San Francisco-Oakland Bay Bridge (Frick, 2015) and the Danjiang Bridge (Spallone, 2017) with medium spans, and quite a few bridges with small spans mentioned in the introduction part. The bridges have contributed to a new trend of landscape bridges addressing all the structural, architectural, and landscape considerations, regardless of the role of the bridge designers.

Living in an era that we are readily delivered over to technology, whether we passionately affirm or deny it, many of us could be utterly blind to the essence of technology if not holistically informed. We are more likely to touch the essence of bridge technology by taking stock of the development trajectory of bridges. Instead of doing mere homage, the manifold interlocking sides of technology leading to both development and retrogression could be discovered. Therefore, the following ponderings are instrumental in deconstructing landscape bridges on their temporal scale:

- (1) How does bridge development benefit from the essence of modern technology?
- (2) In the light of modern technology, what may fade pertaining to the essence of a bridge?
- (3) How to reconcile the relationship between the prevailing and the oblivious? Especially how to reshape the role of technology in designing a landscape bridge?

The way how modern technology held sway in the process of bridge development could be discovered through the investigation of Heidegger's question concerning technology, in which the essence of technology was thoroughly addressed. Instead of focusing on the instrumentality of technology, generally regarded as something neutral, Heidegger defined technology as a way of revealing, bringing concealment into unconcealment. By unlocking, transforming, storing, distributing, and switching about, everything concealed is ordered to stand by as what he called the "standing-reserve". The essence of modern technology is described as what he called "enframing", which demands

ordering of the standing-reserve in the process of revealing (Heidegger, 1954). Envisaged in Heidegger's understanding of technology, the development of modern bridges is exactly the process of revealing, to reveal what should be the most suitable bridge type in accordance with various distances and topographies within the physical and social restraints. The invented bridge types in conjunction with the materials, apparatuses, and instruments are then set upon as the standing-reserves at hand, being brought into an orderable framework for use. Conclusively, the development of bridges is driven by the power of revealing toward presenting of the essence of technology carried out by man.

"The essence of enframing is that setting-upon gathered into itself which entraps the truth of its own coming to presence with oblivion. This entrapping disguises itself, in that it develops into the setting in order of everything that presences as standing-reserve, establishes itself in the standing-reserve, and rules as the standing-reserve" (Heidegger, 1954). As a revealing of the essence of technology, enframing entraps the truth of its own coming to presence with oblivion, slipping into a dangerous situation that every other way of revealing will be driven out. In this oblivion that blocks the self-manifestation of being, enframing may be bereft of its power, while man may also be divested of his consciousness, being as one kind of standing-reserve who manufactures himself in enframing. Being aware of this exclusive and privileged character of enframing, the oblivion of the other possibilities standing by the essential skeleton of enframing (i.e., the modern bridge typology enframed by modern technology) could also be discovered once the dominant enframing confronts danger.

To disclose the nontechnical aspects of bridges, which are inevitably driven out of the technology-based framework characterized by structural typology, bridges built before the industrial revolution deserve a retrospect. In discovering the manifold nontechnical ranges, including topographical, social, political, cultural, religious, and military etc., the most central part particularly suppressed by modern technology could be their intimate relationship with dwelling, or our living space. The modern mega-structures take a more challenging role in overcoming the geographical barriers and supporting the modern vehicles with efficiency and safety, and this concept is more like what Heidegger called "challenging-forth", while the early bridges were more like the "bringing-forth" from the original dwelling space to serve as a link, a supplement, or an extension within it. Sufficient evidence could be found in both western and eastern history. For example, the Chinese Earlier Song dynasty painting "Along the River during the Qingming Festival" (Fig. 4) represents a prosperous life scene around the Rainbow Bridge across Bian Canal, despite its intricate and excellent substructure known as the woven timber arch (Zhou et al., 2018). The Rainbow Bridge has demonstrated how a bridge could have a nontechnical but close interaction with human life in a way currently replaced by the priority of technology.

Based on the understanding of essence of technology and how it held sway in the process of bridge development, the key to reconciling the binary oppositions of bridges on the temporal scale is to redefine the role of technology in a

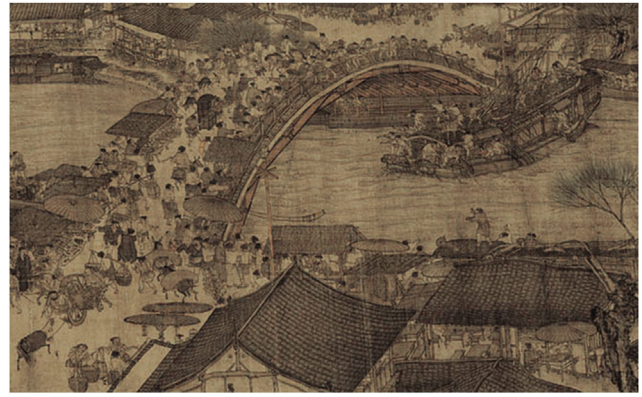


Fig. 4 Rainbow bridge in the Chinese painting — "Along the River during the Qingming Festival". Source: Shanghai Daily, May 24, 2015, Sunday.

more inclusive framework, giving special heed to what has been neglected. Adverse to the danger hidden in enframing, this motivation is also what Heidegger described as the "saving power", which for landscape bridges can only derive from thoughtful architects and engineers, but not those putting great emphasis on the arbitrary enframing. This saving power is not to overturn the hierarchy of the previous framework, it is a much attentive negotiation with it. In conceiving his several bridges located on the Veia Traversina, the Swiss engineer Jürg Conzett adopted the philosophy of "weak thought" proposed by the Italian philosopher Gianni Vattimo when meditating on the position of structural technology (Conzett, 2006). In his 1st Traversina bridge (Fig. 5), Jürg Conzett devised an intricate string structure underneath. Although the substructure is structurally excellent and visually eye-catching, its sincerity is also obvious in supporting the upper path compatible with the mountain environment. Back to the example of the Rainbow Bridge, a similar strategy could also be perceived, within which technology has no strong desire to gain the upper hand to show itself. Instead, it puts itself into a position overlooking the diversified demands of a bridge with self-consciousness. Technology should always cooperate, contribute, and even make a sacrifice when juxtaposed with other aspects, which may be closer to the essence of a bridge in many cases.



Fig. 5 1st Traversina bridge by Jürg Conzett (Conzett, 2006).

4.2. Spatial topographic scale — connection and separation

In nature where no particle of matter can share its space with anything exclusive of itself, the meaning of connection comes out in a complementary way contrived by creatures, especially humanity to reorganize the world. In this sense, a bridge should be the most manifest achievement of human ability. This man-made topographic connection should never be overemphasized in overcoming the obstacles in nature, such as marshlands, rivers, mountains, and oceans. The primary intention of a bridge to connect could then be intensified as long as human successfully overcomes the longer distance and the more complex topography. Besides surpassing nature in a technical way constructed by human, as a connection, a bridge is supposed to be a gathering or assembly of the discrete nature. To illustrate the nature of dwelling, Heidegger used the bridge as an example that gathers itself in its own way: saving the earth, receiving the sky, awaiting the divinities, and initiating mortals (Heidegger, 1971). This gathered fourfold by a bridge should be the exact connection of matter and spirit, including the topography, environment, symbolism, and humanity pertaining to a bridge.

The connection role of a bridge in the described way of overcoming and gathering could be highly praised, especially when it is constructed as a megastructure crossing vast lands, mountains, and waters or an infrastructure contributing to the space renewal of communities. However, this dominant goal to connect is a presupposition of what it has overcome and gathered, i.e., the separation of nature. Connecting and separating are two types of activities that come together in human undertakings, and we are at any moment those who separate the connected or connect the separate (Simmel, 1994). Besides doing homage to bridges contributing to an extremely accessible world for humankind, the manner by which the connection is derived from the separate and inversely affects it must also be investigated to inspire more landscape bridge designs.

In considering the correlation of separateness and connectedness, the German philosopher Georg Simmel made a detailed analogy between a bridge and a door, particularly distinguishing their difference in boundary and

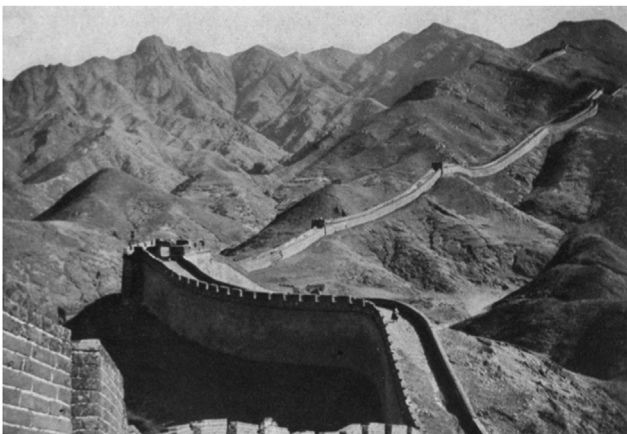


Fig. 6 Great Wall of China (Clapp, 1920).



Fig. 7 Plan Obus for Algiers by Le Corbusier (Ackley, 2006).

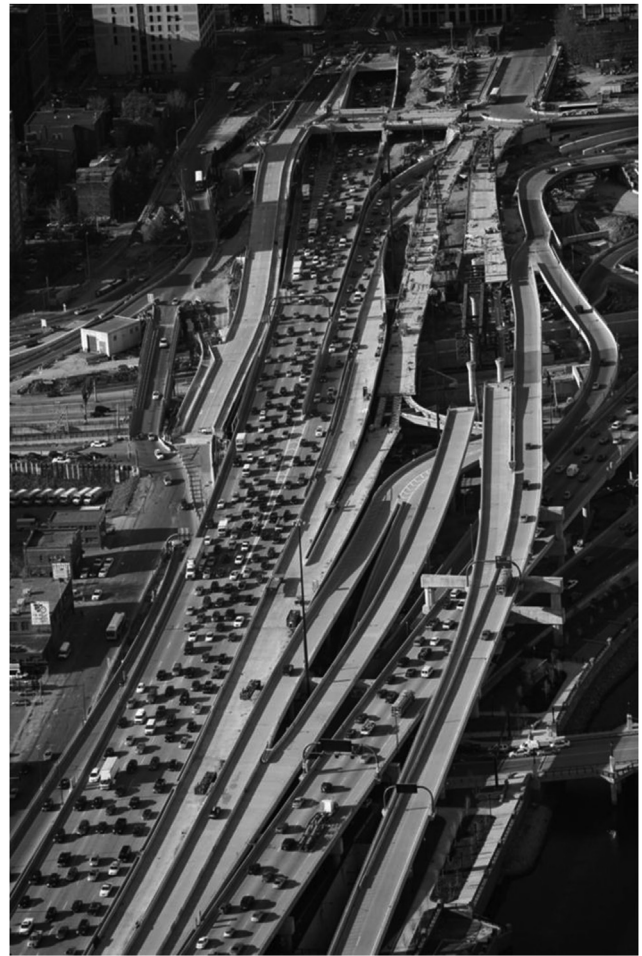


Fig. 8 Central Artery (I-93) before Big (DigHöweler and Yoon Architecture, 2008).

direction issues. As illustrated in his comparative study, the bridge always allows the accent to fall on connection, while the door represents in a more decisive manner how separating and connecting are only two sides of precisely the same act (Simmel, 1994). On the basis of his creative

perspectives, three analogies are made herein to further understand the counterpart of connecting and separating with respect to a bridge, namely, the analogies with the road, door, and rampart. To avoid nihility, four sorted contents belonging to connection and separation will be addressed as follows, which are based on an elaborate deconstruction of this binary opposition.

(1) **Accessibility-inaccessibility:** The road comes out of the surface of the earth by connecting two places that are originally separate. This path-building achievement of humankind reaches its zenith in the construction of a bridge, and both of them dedicate to an accessible route marked by a beginning and end. Then, the bridge could be considered as an extension of the road by overcoming obstacles. When we shift our focus to a similar route-like rampart, the possible danger of inaccessibility somehow occurs. Taking the famous rampart the Great Wall of China for illustration, the primary goal of this mega-infrastructure is to ward off invaders from the northern part of China geographically (Fig. 6). The Great Wall has demonstrated an extreme situation of how the route-like infrastructures may produce transverse inaccessibility when we ordinarily focus on the continuous longitudinal accessibility by blocking from the transverse. Employing a method reminiscent of the one used for Roman aqueducts, the Plan Obus conceived by Le Corbusier in the 1930s was supposed to be a modernist megastructure laid directly over the Casbah of Algiers, with its elevated highway and bridges combined with dwellings (Fig. 7). If built, an abrupt change in the spatial arrangement would take place for its brutal scale (Ackley, 2006). Although initially pursuing ideal traffic accessibility, an imaginable blocking could also be caused by this Utopian roadtown. For comparison, the door, which concentrates on both accessibility and inaccessibility, represents in a more decisive manner how separating and connecting are only two sides of precisely the same act through opening and closing (Simmel, 1994).

(2) **Unity-discreteness:** The Heidegger's fourfold gathering of the earth–sky–mortals–divinities describes the most ideal state of unity a bridge could be. On the one hand, this unity is manifestly embodied in the integration of the isolated places it connects, such as banks of a river. On the other hand, the unity could be reflected in the involvement into a larger unordered system, served as a positive artificial composition to contribute to a well-organized one (e.g., the united landscape characterized by ancient Roman aqueducts and the poetic multipurpose mega-form in Plan Obus expected to be woven into the city landscape). Conversely, a distinguished characteristic of discreteness could be found in the other analogs. Specifically, a road divides what is intact into its bilateral places where discreteness may subsequently emerge. For a door, it makes a strict distinction between inside and outside, which is discreteness-based. And the discreteness on two sides of a rampart is deliberately intensified by topographical separation to guarantee self-independence. Revealingly, possible discreteness may also take place concerning a bridge. In the case of the Plan Obus, disaster loomed in the project's disregard for Algerian social and religious traditions, the segregation of the workers and the European communities (Ackley, 2006), and discreteness of space, culture, and society are simultaneously covered up by the superficial unity. A practical example to comprehend

the discreteness and unity is the High Line Park, which plays a role in the gentrification of its surrounding neighborhoods (Millington, 2015). This type of discreteness is especially mute when the privileged unity speaks. Another type of discreteness probably originates from the inefficiency of the unity itself. The famous Boston Big Dig was designed to stitch back the city that was cleaved apart from the 1950s by installing an underground network of interstate tunnels to replace the elevated I-93 highway, which had culminated into a voluminous complex of unity equivalent to discreteness (Fig. 8).

(3) **Direction-indifference:** A bridge, as a line stretched between two points, prescribes unconditional security and direction. It makes no difference in meaning in which direction one crosses a bridge, whereas the door displays a complete difference of intention between entering and exiting (Simmel, 1994). In Simmel's comparative thinking, the door stands where the finitude and infinitude meet, which is in contrast to the bridge that connects the finite with the finite. The indifferent treatment to the separated sides that a bridge connects is an exact reflection of the common neglect of the differences in the sites awaiting for connection. This phenomenon is particularly noticeable in bridges applying a strict structural typology characterized with symmetrical forms. This insensitivity to the directionality along which a line stretches and the individuality it physically connects is glaringly obvious for roads and ramparts. The beginning and ending of them are negligible compared with their length dimension. Inspired by the extreme cases representing the directionality, bridges with relatively limited length, necessarily require differential treatments to the separate sites with diverse characteristics to be connected.

(4) **Consolidation-fortuitousness:** In illustrating how connection dominates the forming of road, Simmel (1994) put forward that the will to connect is a shaping of things, a shaping that was available to the will at every repetition without still being dependent on its frequency or rarity. We accomplish a solid structure with its intended function (i.e., a road and a bridge to carry traffic and a rampart to defend the territory) only by making it physically lasting. Once built, this consolidation will serve as a permanent element planted in nature with its fortuitousness elevated to a unity. We will get inured to it by using it abidingly and viewing it as a constitutive element of the environment. While for a door, it can shift between the feeling of isolation and connection, which could be achieved and intensified through its closing and opening. The flexibility of a door is absent in a bridge, which freezes the movement into a solid structure and integrates itself into the landscape. Thus, as a solid connection achievement and permanent landscape element, a bridge deserves special functional and aesthetic scrutiny.

A concise and conclusive symbolic representation for illustrating the connection and separation characteristics of the discussed analogies is shown in Table 2.

4.3. Spatial landscape scale — skyphilia and topophilia

Following the overall spatial issue concerning connection and separation, the secondary imperative pertaining to

Table 2 Analogies of a bridge for illustration of its connection and separation characteristics.

Deconstruction of Connection and Separation		Analogy			
		Bridge	Road	Door	Rampart
Connection	Accessibility	●	●	●	○
	Inaccessibility	○	○	●	●
	Unity	●	○	○	○
	Discreteness	○	●	●	●
Separation	Direction	○	○	●	○
	Indifference	●	●	○	●
	Consolidation	●	●	○	●
	Fortuitousness	○	○	●	○

Note: the solid circles represent that the referred characteristics are distinctive, while the hollow circles indicate the indistinct or nonexistent ones.

what we call a landscape bridge should be its relationship between landscape or how we perceive, view, and experience a bridge within its landscape background. In the study of environmental perception, attitudes, and values, the eminent geographer Yi-Fu Tuan structured the theme of “topophilia” to describe the affective bond between people and place or setting (Tuan, 1974). Topophilia embraces an intimate relationship with the environment, society, and culture and finds its gratification in a self-affirmed aesthetic experience. In making the distinction of the traditional society and the modern one, Tuan recognized that primitive and traditional people lived in a vertical, rotary, and richly symbolical world, whereas a modern man’s world tends to be broad of surface, low of ceiling, nonrotary, aesthetic, and profane (Tuan, 1974). Although Tuan did not go further into the antipodal field of topophilia, his differentiated understanding of verticality and planarity connotes another type of relationship between people and the environment, which we may conclude as “skyphilia” as the counterpart of topophilia in this study.

Revealingly, the antitheses of skyphilia and topophilia may share a similar theory with abstraction and empathy, a far-reaching theory of plastic art proposed by Wilhelm Worringer at the beginning of the 20th century, exerting a significant influence on art, architecture, and landscape. Whereas the precondition for the urge to empathy is a happy pantheistic relationship of confidence between man and the phenomena of the external world, the urge to abstraction is the outcome of a great inner unrest inspired in man by the phenomena of the outside world (Worringer, 1997). Recurrent antipodal descriptions were made by Worringer to distinguish these two artistic volitions, such as beauty of the organic and beauty of the life-denying inorganic, self-affirmation and self-alienation, and representation of space and suppression of space, corresponding to

the aesthetic experiences of empathy and abstraction, respectively. As Worringer addressed, the aim of abstraction was to wrest the object of the external world out of its natural context, out of the unending flux of being, to purify it of all its dependence upon life (i.e., of everything about it that was arbitrary), to render it necessary and irrefragable, to approximate it to its absolute value (Worringer, 1997). This absolute value corresponds to a transcendental tinge to all notions, escaping from our empathetic world to its inanimate material individuality, close to the supposed meaning endowed with the new-making word “skyphilia”.

In a narrow sense, skyphilia is the urge to transcend the complex of the profane world that man dwells in, to emerge towards the sky with forms of determination, purity, and inanimateness, and eventually to achieve its absolute value of material individuality. It is the concrete reflection of abstraction with its own specialized directionality. In man-made achievements, skyphilia pursues its transcendence, in most cases skywards, standing as symbolic high-rise structures. This transcendence of nature could be found in numerous tall buildings with strong symbolic images, ranging from the primitive societies to modern metropolis, such as the Babel Tower, the Egyptian Pyramids and Obelisks, the Eiffel Tower, the Sagrada Familia, the Burj Khalifa Tower, and the eminent Golden Gate Bridge, which herein is used for a comparative study to represent the cable-stayed and suspension bridges with tall towers. Despite the height difference of these structures due to the diverse architectural functions supported by diverse materials and construction technologies of the time, they all rise from their rooted landscape ground as a prominent landmark with symbolic implications. In analyzing the motivations of these tall buildings, besides their functional requirements to provide architectural

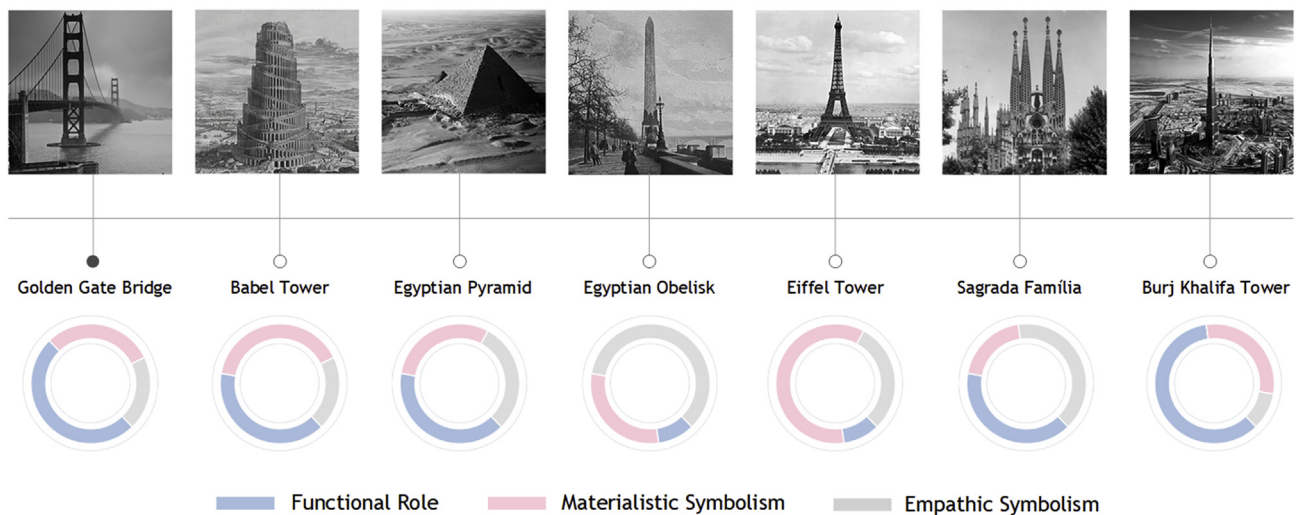


Fig. 9 Comparative motivation analysis of high structures.

space or structural support, their fervent urge to symbolism could be further explored to involve both a materialistic and empathetic consideration. As the comparative study illustrated in Fig. 9, in the functional aspect, the skyscraper Burj Khalifa Tower and the long-span Golden Gate Bridge stand as the most effective structures necessary for their functional goals. By contrast, the obelisks and the Eiffel Tower were constructed without any functional expectations. Instead, the grandiose edifices were born with a specific aim for symbolism, being monuments of religious belief and social development, respectively. The difference is that the Eiffel Tower was endowed with more symbolic implications of material individuality built of wrought iron to stand as the tallest building of the time, while a more empathetic symbolism of religion was expected for the obelisks in all ages incessantly. By contrast, the motivations to build the Babel Tower, the Egyptian Pyramid, and the Sagrada Familia are more balanced in relation to their functional requirement, the symbolic will to skyphilia and the empathetic representation.

The urge to abstraction stands at the beginning of every art, and in the case of certain peoples at a high level of culture remains the dominant tendency (Worringer, 1997). The similar artistic volition of skyphilia is also proven to be

dominant when conceiving a landscape bridge. We are automatically inclined to preconceive a picturesque landscape with the visually symbolic bridge settled in as long as its aesthetic aspects are considered. A vertical, egocentric, and richly symbolic bridge is universally preferred by engineers to present the structural art, or by architects as an effective medium to transcend and activate the original site that may be barren, inanimate, or undeveloped. Many bridge works of Calatrava are typical illustrations of how skyphilia acts as an invisible power to contribute to their success. For example, the Alamillo Bridge (Fig. 10) is the application and scale-up of his sculpture work of Musical Star to a civil engineering structure (Guest et al., 2013). Calatrava has promoted the concept of abstraction to its absolute value with grandiose dimension by enlarging the scale of the abstract sculpture, thus making an extremely positive impact on the landscape improvement for the 1992 Universal Exposition hosted on La Cartuja. Driven by the urge of skyphilia, the significance of the Alamillo Bridge to La Cartuja resembles that of the Golden Gate Bridge to the San Francisco Bay, the pyramid to Sahara, and the Eiffel Tower to Paris.

Although the artistic volition of Skyphilia of a landscape bridge is to transcend nature, in the end, it fits into the

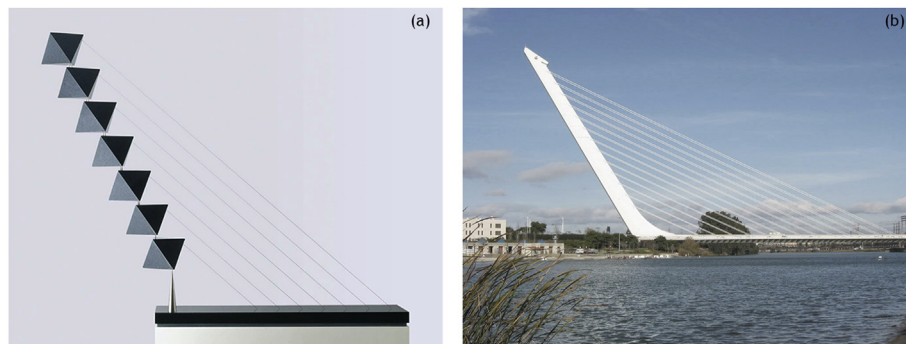


Fig. 10 Skyphilia: sculpture into bridge by Santiago Calatrava. (a) Sculpture Musical Star 1 (Mark, 2014); (b) Alamillo Bridge. Source: Photo Credit belongs to Wikiarquitectura

image of nature as a landscape element. A bridge gains its spiritual expectation of Skyphilia only by means of its immediate spatial visibility. When delineating the man's perceptual equipment as a biological organism, Yi-Fu Tuan pointed out that responding to the world through sight differs from responding to it through the other senses; the world perceived through the eyes is more abstract than that known to us through the other senses, and we have the tendency to regard seen objects as "distant" — as not calling forth any strong emotional response — even though they may in point of fact be close to us (Tuan, 1974). Whereas skyphilia is a more vision-based tendency to transcend nature, topophilia is empathetically rooted in the world we perceive with biological senses of vision, touch, hearing, and smell, and it is the same world we live in with environmental, cultural, and individual differences. In this meaning, a bridge should not only be built to be seen but also to be experienced by crossing, lingering, recreating, and resting. Unlike the topographical transcendence of skyphilia, the topophilia of a bridge embraces the world pragmatically.

Topography, or geography, including the land features of a place, its environment, and inhabitants, necessarily provides the content of topophilic sentiment, and together with our human perceptual system, they constitute the key elements of Tuan's topophilia (i.e., the perception, attitudes, and values). The Fort Vancouver land bridge (Fig. 11), an antipodal example of skyphilia, appropriately illustrates how topophilia interacts with the world in a positive way to be close to it. Spanning American State Route 14, the Land Bridge was built to restore the ancient crossroads of the Klickitat Trail and the Columbia River. An interpretive trail with educational components is specially planned to invite multiple levels of rich historical, cultural, and environmental interpretation in this project, including indigenous geography, history, language, and plants. The bridge path appears as a natural extension of the existing landscape, and all patterns, shapes, and artworks become an open book of the site's history; it brings together all the elements into one masterpiece, being an emblematic icon for the Confluence Project and the city (Land8: Landscape Architects Network, 2014).

The transcendent skyphilia and the immersive topophilia are not contradictory oppositions, except their distinctive features. Before skyphilia has realized its ideal enclosedness, it must have considered for a moment how to distance itself from the bewildering ground when taking root in it. A spatial, historical, and spiritual extension of the orchestrated world is also expected by topophilia to gain satisfaction beyond the empathetic fulfillment of the living world. A harmonious combination of skyphilia and topophilia could find its exact representation in the form of the ancient Roman aqueducts crossing the valleys. The bridge of the towers (Ponte delle Torri), a Roman-Lombard aqueduct in Spoleto of Italy, is an imposing bridge that unites the Sant'Elia hill (the highest point of the city of Spoleto) to Monteluco at a unique height (Fig. 12). With 236 m long and approximately 80 m high, the bridge presents both a vertical and longitudinal dimension corresponding to its grounded topography. Nine pillars linked by pointed arches rise from the valley between the two hills, while the first two tallest are based on a previous building site alluding to



Fig. 11 Topophilia: Fort Vancouver land bridge (Land8: Landscape Architects Network, 2014).

the approachable plane on which man lives. With a shift from topophilia to skyphilia, the bridge gives access to the Albornoz Castle on a particular height, which is located on the top of the Sant'Elia hill and from where you can enjoy a splendid panoramic view over Monteluco. Thus, the transcendental traits of the castle and the bridge are mutually intensified, making them the two most important emblematic symbols of Spoleto, characterized by a mediated emotion of skyphilia and topophilia.



Fig. 12 Skyphilia and Topophilia: Ponte delle Torri. Source: Google Maps, Photo Credit belongs to Marco Corbella.

4.4. Spatial architectural scale — extroversion and introversion

According to Merriam-Webster Dictionary, extraversion (also spelled as extroversion) is the state of primarily obtaining gratification from outside oneself, while introversion is the state of being predominantly interested in one's own mental self. The theory of extroversion and introversion was preliminarily popularized by Carl Jung, an influential thinker and the founder of Analytical Psychology, to distinguish the central dimension of human personality (Jung, 1921). Jung (1995) defined extroversion as “an attitude-type characterized by concentration of interest on the external object”, and introversion as “an attitude-type characterized by orientation in life through subjective psychic contents”.

The extroversion-introversion of architecture has long been one of the most refreshing issues of modernity because architecture ordinarily presents distinctions between the interior and the exterior. Among them is the prevailing dictum “form follows function” proposed by Luis Sullivan, which has testified to a wide-ranging influence on the modern architecture of the 20th century. In the post-modern period, two realms of inquiry are distinguished in regard of the question of what constitutes a proper architecture. The first realm tended toward the horizon of interpretation and design by a “scientific view” of getting to know nature. This realm is also considered environmental-extroverted, looking for the truths that lie outside the body of architecture. The second realm emphasized architectural discourse toward the world of architectural objects advocating a kind of autonomous-introverted architecture, which is characterized by a tendency to adhere to the rhetorical domain of architectural objects as for organizing compositional principles (Xhambazi, 2015).

The widespread discourse of the diametrical opposition of architecture's extroversion and introversion is highly associated with space theories, including boundary issues. In spite of the subsequent theories to blur and mediate the interior and exterior through form and boundary strategies, architecture generally occurs at the meeting of the interior and exterior, where space is born in the form of concrete boundaries, such as walls to define the limits. While for the modern bridge, despite its early contribution to the advent of architectural modernism, it has been excluded from the mainstream of the space theories in conjunction with boundary consideration. The extroversion–introversion dichotomy is seldom mentioned to address the architectural aspect of a bridge when two extreme situations normally take place. On the one hand, a bridge is considered as an open space with indeterminate boundaries. On the other hand, it is treated as a building crossing a particular site characterized by typical architectural enclosedness. Before we could distinguish between the extroversion and the introversion of a bridge, the construction of a spatial hierarchy borrowing space and boundary theories from architecture is indispensable to offer the basis for both an extrovert and introvert architectural strategy for a bridge. Thus, the three space levels defined herein are as follows:

(1) **Box:** the first space level defined by the main body of a bridge, physically corresponding to its functional and perceptible space created inside or on the constituent architectural components. With regard to bridges with typical enclosing components similar to that of architecture, the “box” is roughly equivalent to its geometric figure, such as cube, cylinder, pyramid, and prism, whose interior and exterior of the main body could be easily grasped. In terms of bridges with no determinate enclosing geometrical space, namely, those with complex geometries and characterized by open space, the “box” could be deemed as the minimum space to encompass all the functional space, including architecture, traffic, and recreation. A visualized way to comprehend the “box” without noticeable enclosing space could refer to the environmental artwork “The Pont Neuf Wrapped” by artists Christo and Jeanne-Claude. Through wrapping the bridge body with fabric in a way analogous to clothing, this work reminds us of the boundary between the supposedly intrinsic self or body it surrounds and the outside world (Salinger, 2007). Thus, the “box” space could be imagined by dressing the architectural body of a bridge. It is a simplified manifestation of bridge space regardless of its original complexity of geometry.

(2) **Boundary:** the second space level to describe a bridge within its site scale, mainly focusing on the relationship between the geometric appearance and the site around it. “Boundary” is about how we define, limit, and create a portion of land distinct from the rest of the universe and to assign a particular role to it in consideration of its effect as a constituent landscape element in a broader nature space. Unlike the common boundary concept of architecture that exactly defines the interior and exterior of the main body, the “boundary” of a bridge serves as a dual role in a more flexible way when it has to negotiate with the geometric appearance of the main body and involve itself into the site at the same time. Not restricted to the absolute geometry of a bridge, boundary implies a more fluid logic of connectivity derived from the main body (i.e., the previously illustrated “Box”). In searching for the possible forms of the blur boundary, the “box” could be considered a “blob”, which has an organic form that is soft and free-flowing. However, it does not mean that the “Box” should be turned into a physical form of “Blobitecture”. In many cases, the liquidity of the boundary associated with the “Box” is more ideological and implicit, creating impalpable but subsistent transitions to involve itself into the broader space imperceptibly.

(3) **Territory:** the third space level to observe the widest affected space owing to a bridge's existence. According to the definition contributed by the French philosopher Gilles Deleuze, “Territory” evades easy categorization because the territory itself is a malleable site of passage rather than being a sedentary place maintaining firm borders against outside threat (Parr, 2010). As an assistant illustration, Deleuze introduces his important notion of “assemblage” that “swings between territorial closure that tends to reterritorialize them and a deterritorialising movement that on the contrary connects them with the cosmos” (Parr, 2010). The territory of a bridge is an assemblage of all the

architectural elements and their relevant surroundings in an organized way (territorialize). The bridge stands as one of the constituent and influential landscape elements within its territory, whether it is centralized or decentralized, dominant or accompanied. Meanwhile, the territory of a bridge is entitled to a dynamic border (deterritorialize) to evaluate the bridge for different purposes. At particular times and from various perspectives, the border builds not only the architectural connections with the outside nature but also the non-architectural ones, such as the social, cultural, and economic aspects, which may indirectly influence the architectural space representation. The territory of a bridge manifests a series of heterogeneous elements, including its architecturally affected space and the other constantly changing circumstances.

The distinguished three space levels pertaining to a landscape bridge are illustrated on the left of Fig. 13. On the right portion of the figure is the diagram comprised of both an extroversion-based and an introversion-based design process, constructed layer-by-layer on the three space levels. The process starting from In-1 to In-5 demonstrates how the constituent architectural elements of a bridge could emerge as a landscape element that seamlessly fits into nature when following an introversion-based trail. Meanwhile, the extroversion-based trail starting from Ex-1 to Ex-5 adopts a reverse strategy prioritizing a bridge's figure in its surroundings. The specific approaches implemented between the constructed space levels could be further elaborated as follows, corresponding to the two opposite processes.

An extroversion-based design strategy is generally adopted to dedicate to a picturesque landscape when conceiving an exotic landscape bridge within it. Focusing more on the environment that a bridge will settle into, the extrovert strategy seeks to gain gratification based on a presupposed and well-bedded understanding of the environment lying outside the main body of the bridge. The practical steps may include the following: (1) territorialize the field out of nature; (2) qualify the boundary within the

territory; (3) embody the box associated with the boundary; and (4) materialize the box with its constituent architectural components (Fig. 13). An appropriate environmentally extroverted demonstration is the Lucky Knot Bridge (Fig. 14) in Changsha, China. The bridge is set to be a landmark attraction over the Dragon King Harbour River in the rapidly developing "New Lake District" of Changsha (territorialize). Moreover, the bridge is supposed to connect multiple levels at different heights, including river banks, roads, higher-placed parks, and interconnections (qualify). On the left of Fig. 14, inspired by the Mobius ring and the Chinese knot symbolizing luck and prosperity, the Knot Bridge with eye-catching form and color rises as an environmentally predominant landscape element, which is comprised of three red undulating, intertwined steel walkways (embody) by explicitly engaging itself with the local context. Furthermore, the steps, platforms, and intersections are well organized within the rings to offer the recreational space for tourists and passers-by attracted by this environmental-extroverted landmark (materialize).

By contrast, an introversion-based design strategy greatly emphasizes the architectural components and how they contribute to a well-organized space inside/on the bridge, with considerations that normally stop at its geometric appearance in the environment. The applicable steps may include the following: (1) spatialize the bridge by using its constituent architectural elements; (2) blur the boundary that surrounds the spatialized box; (3) involve the boundary into a territory; and (4) deterritorialize the territory into nature. As a comparison, the Qingpu Pedestrian Bridge in Shanghai (Fig. 15) adopts an entirely different design procedure to deal with the issue of extroversion–introversion. In Fig. 15(a), the bridge is initially conceived to provide for a dedicated truss on the river offering changing perspectives along the bent pass inspired by the winding gallery of the traditional Chinese garden (spatialize) while responding to the different access conditions at the two banks (blur). The bridge visually adapts itself to the surroundings (involve) by adjusting its

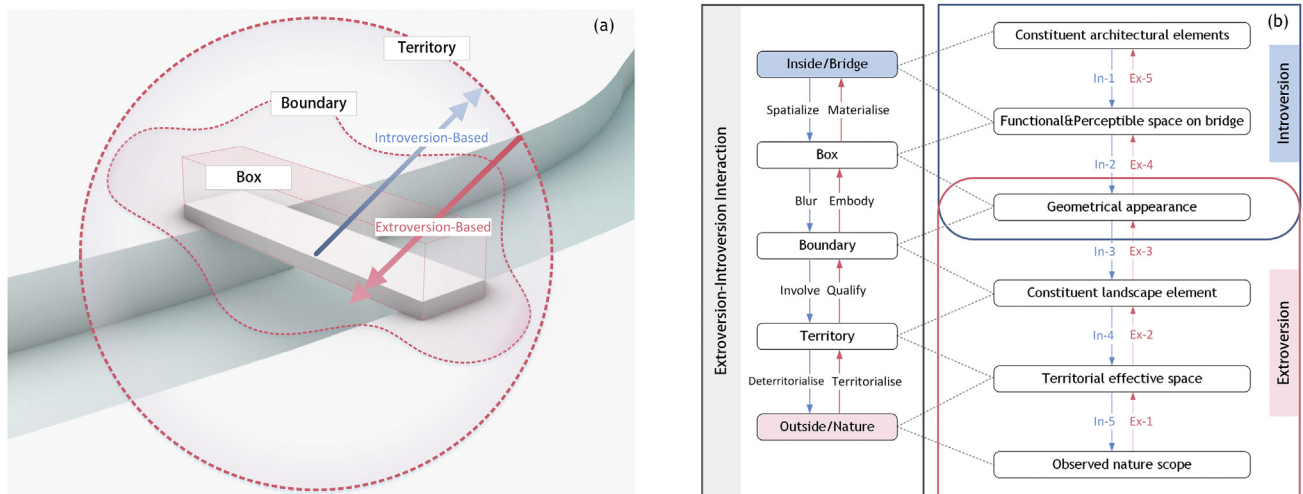


Fig. 13 Extroversion–introversion of a bridge. (a) spatial hierarchical analysis of a bridge; (b) crystallization of the spatial hierarchy in conjunction with the two inverse design procedures of extroversion and introversion.

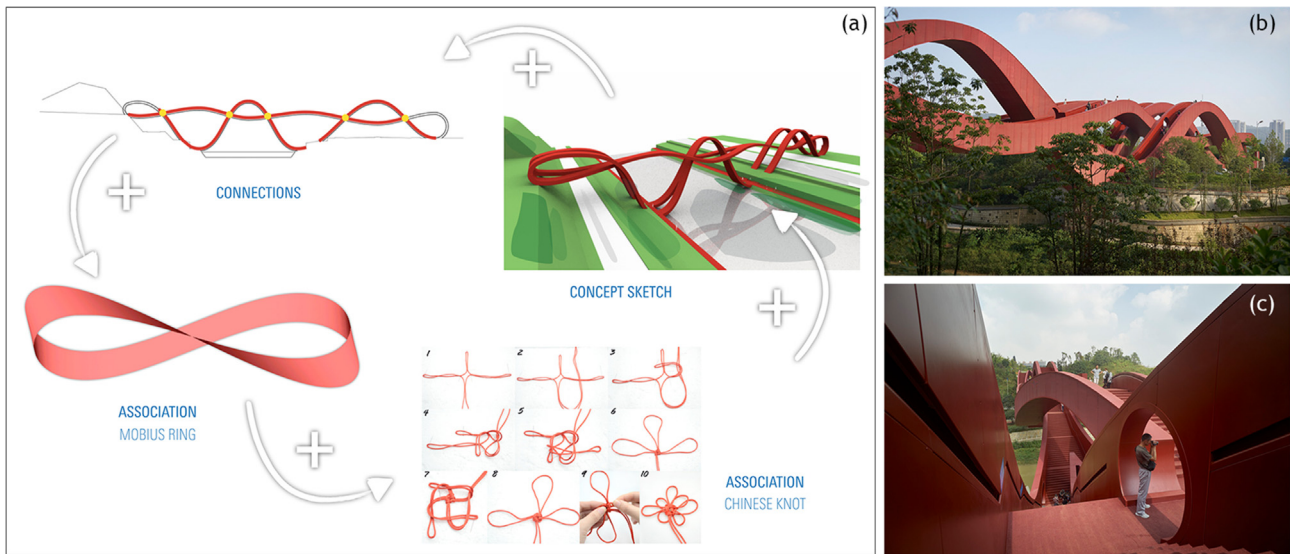


Fig. 14 Extroversion-based process: Knot Bridge at Chengdu, China. (a) Bridge conceived as a landscape element. (b) embodied form of the bridge; (c) materialized space on the bridge. Source: Archdaily, Photo Credit belongs to NEXT architects and Julien Lanoo.

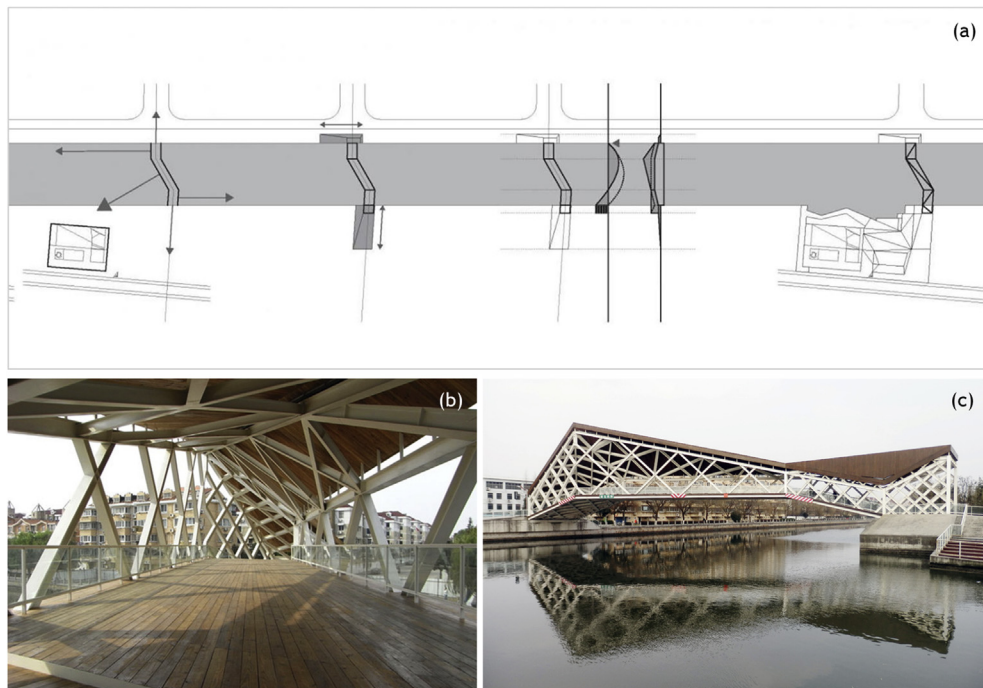


Fig. 15 Introversion-based process: Qingpu Pedestrian Bridge at Shanghai, China. (a) Formation of the main body and its boundary on the basis of an introverted deduction (Alba, 2009); (b) constituent elements of the truss shaping the box of the bridge; (c) geometrical appearance involved in the environment. Source of (b)&(c): Archdaily, Photo Credit belongs to CA-DESIGN and Nacasa & Partners.

elevation and roof and serves as a central public space for the connected communities (deterritorialize).

When we talk about human personality, extroversion tends to be manifested in outgoing, talkative, energetic behavior, whereas introversion is manifested in a more reserved and solitary behavior. The trait differences are somehow equivalent to the extroversion and introversion of

a bridge, corresponding to a heteronomous and autonomous presentation, respectively. Whereas extroversion is always appreciated for its consideration about the external world, ambiversion is moderately integrated and exhibits qualities of both introversion and extroversion. The corpus of awareness, knowledge, strategy, and practice appears intertwined within both the realms, namely, introversion

and extroversion, although connecting the defined space levels in opposite ways. A landscape bridge that comprehensively addresses its architectural aspects is more like an ambivert considering autonomy and environment, regardless the type of procedures it adopts (either extroversion- or extroversion-based).

5. Multi-scale integration: a pyramid model

The extensive investigation of the multiple temporal–spatial scales of a bridge based on the deconstruction theory builds a hierarchical system comprised of the discovered oppositions, namely, development and retrogression, connection and separation, skyphilia and topophilia, extroversion and introversion. By thoroughly addressing their dominant and subordinate sides, the dual oppositions reestablish themselves through giving sufficient attention to the ordinarily overlooked aspects and calling for a new relationship between the oppositions, namely, a peaceful coexistence or a complete reversal. Within the deconstructed scales, a landscape bridge could draw its design inspiration from either pole of the oppositions or an appropriate combination. In addition, the constructed multiple scales are not physically isolated in their respective autonomies; on the contrary, they are highly associated in the cross-scale mechanism in which every scale releases its boundary and actively interacts with the adjoining scales.

As shown in Fig. 16, a pyramid-form model is founded by integrating the discovered multiple scales and oppositions of a landscape bridge. The stabilized triangle emerges as a prototype that not only explains how the current scales constitute this primitive framework, but also provides interfaces for the other scales to be further discovered or developed. Revealingly, the scale closer to the foundation of the pyramid is also prioritized to define a landscape bridge, i.e., from a dominant expression, a bridge could be a connection, a picturesque landscape element, and a well-shaped architecture in a sequence. The latter developed scales with growing vitality are generally closer to the top of the pyramid, which is elevated by the development of bridges and contributing to the enrichment of the pyramid ceaselessly. Neither part of the binary oppositions in the pyramid model could exist without the interaction force

from the other parts. The multiple scales are actually interdependent regardless of our general neglect of the foundation and the opposite side of the pyramid. Specifically, the pyramid model may inspire various design strategies by combining of deconstructed components taken from different scales (e.g., a landscape bridge could be appropriate coordination of skyphilia, topophilia, and extroversion, considering the retrogressive aspects at the meanwhile). The deconstructed multiple scales are interwoven into a new hierarchy while reestablishing themselves and consolidating the pyramid model.

6. Conclusion

In view of the scarcity of design theories for contemporary landscape bridges, this research mainly aims to investigate landscape bridges on the basis of their multiple temporal–spatial scales, namely, (1) temporal scale, (2) spatial topographic scale, (3) spatial landscape scale, and (4) spatial architectural scale. Unlike the previous bridge design theories focusing on pure structural, architectural, and landscape aspects or calling for interdisciplinary cooperation, our work provides a broad framework to help the individual reader in placing his or her interests and note how they are related to the specific themes of landscape bridges. This work is devoted to the common theory that inspires both bridge engineers and architects.

Following an elaborate investigation in the introduction part addressing the research and design status of landscape bridges, a multifaceted framework is proposed to cover the most central issues with respect to a landscape bridge. The new multi-scale framework is instrumental in understanding landscape bridges in a comprehensive and open-minded view. The dominant and opposite counterparts are thoroughly addressed with their consistency strategies discussed by observing the four scales based on Derrida's deconstruction theory. The main conclusions are as follows:

(1) **Development and retrogression:** On the temporal scale, the span capacity and current situations of the four main modern bridge types were clearly illustrated by the investigation of the span development and a periodization analysis. The results showed that we are following a gradual development route in the new century when digesting technological achievements and make non-structure-driven innovations on the previously founded technological strength. The positions of development and retrogression of bridges were reinterpreted on the basis of Heidegger's theory of "enframing" concerning technology. The technology should always cooperate, contribute, and even make a sacrifice instead of dominating when juxtaposed with other aspects of a bridge.

(2) **Connection and separation:** On the spatial topographic scale, we used three analogs, namely, road, door, and rampart, to help to understand the connotation of connection and separation on the basis of Georg Simmel's comparison between bridge and door. The specifically addressed issues included accessibility and inaccessibility, unity and discreteness, direction and indifference, consolidation and fortuitousness. We confirmed that except doing mere homage to the connecting role of a bridge, the separation also happens in many ways, which should be

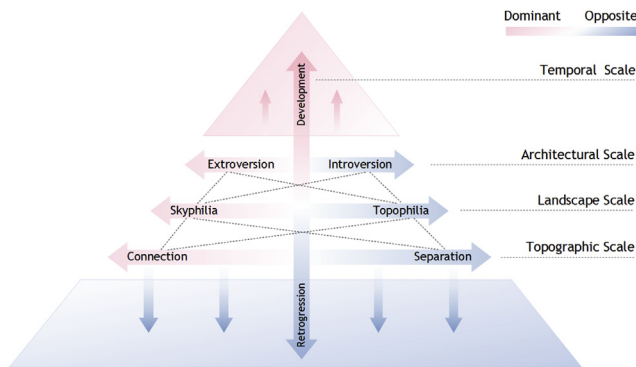


Fig. 16 Pyramid model of landscape bridges based on a multi-scale integration.

carefully avoided and could be appropriately utilized to inspire the connection.

(3) **Skyphilia and topophilia:** On the spatial landscape scale, the antipod of Tuan's topophilia was proposed as skyphilia to introduce the two common landscape patterns of bridges. We distinguished the characteristics of the transcendent skyphilia and the immersive topophilia through a theory discussion similar to that of Worringer's abstraction and empathy. Both concepts are indispensable in the landscape scale and could unite as one composite landscape mode in many cases.

(4) **Extroversion and introversion:** On the spatial architectural scale, three spatial levels were defined as box, boundary, and territory to orientate the way we conceive the architectural aspects of a bridge, namely, the environmental-extroverted and the autonomous-introverted strategies characterized by different implementation procedures, which may refer to different emphases but could also be mediated as an ambiversion in practice.

A pyramid model was proposed to integrate the multiple scales. On this basis, we can clearly find that the multifaceted scales are interdependent with each other, while their dominant and opposite sides are exactly positioned. Various design traits could be acquired from this currently overwhelming framework, manifesting a fluid logic of connectivity.

This research is supposed to lead to a series of studies based on multiple scales to be continued. We hope that this work could conceptually inspire bridge designers with dissimilar backgrounds, and peers in this field could derive more stimulus from it.

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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.

References

- Ackley, B., 2006. Blocking the casbah: Le Corbusier's Algerian fantasy. Available online at: <https://www.bidoun.org/articles/le-corbusier-s-algerian-fantasy>. (Accessed 15 April 2021).
- Alba, P.P.A., 2009. More than a bridge: Shanghai Qingpu footbridge design. *Archit. Technol. Des.* 2009, 82–87 (02) (in Chinese).
- Architects, F., Feichtinger, D., 2008. Simone de Beauvoir footbridge, Paris, France, 2006. *World Architect*. 2008 (1), 38–43 (in Chinese).
- Baker, B., 1884. *The Forth Bridge*. Bedford Press, London.
- Beade-Pereda, H., McElhinney, J., Barbulescu, B., 2019. St. Philips footbridge in Bristol: a holistic design as a driver for urban regeneration. *Bautechnik* 96 (2), 133–141.
- Beck, H., Cooper, J., 2012. *Kurilpa Bridge*. Images Publishing, Melbourne.
- Becker, A., Lampe, S., Negussie, L., Schmal, P.C. (Eds.), 2018. *Ride a Bike!: Reclaim the City*. Birkhäuser, Basel.
- Bellini, O.E., Bellini, O.B., Daglio, L., 2008. *New Frontiers in Architecture: Dubai between Vision and Reality*. White Star Publishers, Novara.
- Billington, D.P., 1985. *The Tower and the Bridge: the New Art of Structural Engineering*. Princeton University Press, Princeton.
- Billington, D.P., 1989. *Robert Maillart's Bridges: the Art of Engineering*. Princeton University Press, Princeton.
- Billington, D.P., Gottemoeller, F., 2000. Bridge aesthetics—structural art. In: Chen, W.F., Duan, L. (Eds.), *Bridge Engineering Handbook*. CRC Press, Boca Raton.
- Brumer, M., Rothman, H., Fiegen, M., Forsyth, B., 1966. Verrazano-narrow bridge: design of superstructure. *J. Construct. Div.* 92 (2), 23–70.
- Castañón, C., Serrano, A., Calzon, J.M., 2014. Arganzuela Helix footbridge. *Struct. eng. Int.* 24 (1), 92–95.
- Clapp, F.G., 1920. Along and across the Great Wall of China. *Geogr. Rev.* 9 (4), 221–249.
- Conzett, J., Mostafavi, M., 2006. *Structure as Space: Engineering and Architecture in the Works of Jürg Conzett*. Architectural Association, London.
- Cossons, N., Trinder, B.S., 2002. *The Iron Bridge: Symbol of the Industrial Revolution*. Phillimore & Co Ltd, West Sussex.
- Dallard, P., Fitzpatrick, A.J., Flint, A., Le Bourva, S., Low, A., Ridsdill Smith, R.M., Willford, M., 2001. The London millennium footbridge. *Struct. Eng.* 79 (22), 17–21.
- Derrida, J., 1972. *Positions*. Nouvelles Editions Latines, Paris.
- Derrida, J., 2016. *Of Grammatology*. JHU Press, Baltimore.
- DigHöweler and Yoon Architecture, 2008. *Public Works: Unsolicited Small Projects for the Big Dig*. Available online at: <http://www.howeleryoon.com/research/1254/public-works-unsolicited-small-projects-for-the-big-dig>. (Accessed 15 April 2021).
- Fisher, D., 1982. Design and construction of the Humber Bridge. *Phys. Educ.* 17 (5), 198.
- Frick, K.T., 2015. *Remaking the San Francisco-Oakland Bay Bridge: A Case of Shadowboxing with Nature*. Routledge, Abingdon.
- Gottemoeller, F., 1998. *Bridgescape: the Art of Designing Bridges*. John Wiley & Sons, Hoboken.
- Guest, J.K., Draper, P., Billington, D.P., 2013. Santiago Calatrava's Alamillo bridge and the idea of the structural engineer as artist. *J. Bridge Eng.* 18 (10), 936–945.
- Guillemette, L., Cossette, J., 2006. *Deconstruction and Difference*. Available online at: <http://www.signosemio.com/derrida/deconstruction-and-difference.asp>. (Accessed 15 April 2021).
- Heidegger, M., 1954. The question concerning technology. In: Hanks, C. (Ed.), *Technology and Values: Essential Readings*. John Wiley & Sons, Hoboken, pp. 99–113.
- Heidegger, M., 1971. Building dwelling thinking. In: *Poetry, Language Thought*, vol. 154, pp. 1–26.
- Hermawati, R.L., Hua, C., 2017. Creating urban water resilience: review of China's development strategies "sponge city" concept and practices. *Indones. J. Plan. Dev.* 2 (1), 1–10.
- Ito, M., Endo, T., 1994. The Tatara bridge-world's longest cable-stayed span. In: *Structures Congress XII*, Atlanta, pp. 677–682.
- Iyengar, H., Rockey, C., Sinn, R., Zils, J., 2006. Millennium park BP pedestrian crossing, Chicago, USA. *Struct. Eng.* 84 (13), 33–37.
- Jodidio, P., 2019. *Calatrava: Complete Works 1979-Today*. Taschen, Köln.
- Jung, C.G., 1921. *Psychologische Typen*. Rascher Verlag, Zurich.
- Jung, C.G., 1995. *Memories, Dreams, Reflections*. Fontana Press, London.
- Khoroshev, A.V., Dyakonov, K.N., 2020. *Landscape Patterns in a Range of Spatio-Temporal Scales*. Springer.
- Knight, M., 2014. *The design of the merchant Square footbridge, London. In: Footbridge 2014—Past, Present & Future*, London.
- Kouwenhoven, J.A., 1982. The designing of the Eads bridge. *Technol. Cult.* 23 (4), 535–568.

- Land8: Landscape Architects Network, 2014. Land Bridge Is an Ecological Masterpiece. Available online at: <https://land8.com/land-bridge-is-an-ecological-masterpiece/>. (Accessed 15 April 2021).
- Leonhardt, F., 1968. Aesthetics of bridge design. *PCI J.* 13 (1), 14–31.
- Leonhardt, F., 1984. *Bridges: Aesthetics and Design*. The MIT Press, Cambridge.
- MacDonald, D., Nadel, I., 2013. *Golden Gate Bridge: History and Design of an Icon*. Chronicle Books, San Francisco.
- Mark, R., 2014. *Santiago Calatrava: Sculpture into Architecture*. Available online at: <https://the189.com/sculpture/santiago-calatrava-sculpture-into-architecture/>. (Accessed 15 April 2021).
- Matsumoto, H., Yasuda, M., 1990. Design and construction of the Akashi Kaikyo bridge. *Civ. Eng. Jpn* 29, 45–60.
- McCullough, D., 2012. *The Great Bridge: the Epic Story of the Building of the Brooklyn Bridge*. Simon & Schuster, New York.
- Millington, N., 2015. From urban scar to “park in the sky”: terrain vague, urban design, and the remaking of New York City’s High Line Park. *Environ. Plan. A* 47 (11), 2324–2338.
- Mock, E.B., Kassler, E.B., 1950. *The Architecture of Bridges*. Museum of Modern Art, New York.
- Monclús, F.J., 2009. *International Exhibitions and Urbanism: the Zaragoza Expo 2008 Project*. Ashgate Publishing Ltd, Aldershot.
- Morgen, K., Lüdders, J., 2017. Die butterfly bridge in Kopenhagen. *Stahlbau* 86 (1), 78–83.
- National Research Council (US). Transportation Research Board, 1991. *Bridge Aesthetics Around the World*. Transportation Research Board.
- Office of Bridges and Structures, 1995. *Aesthetic Guidelines for Bridge Design*. Minnesota Department of Transportation.
- Olson, D.W., Wolf, S.F., Hook, J.M., 2015. The tacoma narrows bridge collapse. *Phys. Today* 68 (11), 64–65.
- Özçakı, M., 2017. Creating living urban spaces. *Humanitas-uluslar. Sos. Bilimler Dergisi* 5 (10), 205–228.
- Palladio, A., 2002. *The Four Books on Architecture*. The MIT Press, Cambridge.
- Parr, A. (Ed.), 2010. *Deleuze Dictionary Revised Edition*. Edinburgh University Press, Edinburgh.
- Paxton, R.A., 1977. Menai Bridge (1818–1826) and its influence on suspension bridge development. *Trans. N.com. Soc.* 49 (1), 87–110.
- Pipinato, A., 2015. The history, aesthetics, and design of bridges. In: Pipinato, A. (Ed.), *Innovative Bridge Design Handbook: Construction, Rehabilitation and Maintenance*. Butterworth-Heinemann, Oxford, pp. 3–17.
- Pipinato, A., 2016. Case study: the Russky bridge. In: Pipinato, A. (Ed.), *Innovative Bridge Design Handbook: Construction, Rehabilitation and Maintenance*. Butterworth-Heinemann, Oxford, pp. 671–680.
- Rockland, M.A., 2020. *The George Washington Bridge: Poetry in Steel*. Rutgers University Press, New Brunswick.
- Rossiter, J., 2008. A critical analysis of the Ganter bridge, Switzerland (1980). In: *Proceedings of the Annual Bridge Engineering 2 Conference*, Bath, pp. 81–90.
- Salinger, V., 2007. *The Pont Neuf Wrapped: Framing the Bridge, Bridging the Frame* (Doctoral dissertation).
- Shannon, K., Smets, M., 2010. *The Landscape of Contemporary Infrastructure*. NAI Publishers, Rotterdam.
- Shushkewich, K., Engineers, K.B., 2013. The story of eugene Freyssinet. *Concr. Int.* 35 (10), 47–52.
- Simmel, G., 1994. Bridge and door. *Theor. Cult. Soc.* 11 (1), 5–10.
- Simondon, G., 2012. On techno-aesthetics. *Parrhesia* 14 (1), 1–8.
- Spallone, R., 2017. In the space and in the time. Representing architectural ideas by digital animation. In: *Proceedings of the International and Interdisciplinary Conference IMMAGINI?*, Brixen.
- Sweetman, B., 1997. The deconstruction of western metaphysics: Derrida and Maritain on identity. *Postmodernism Christ. Philos.* 1997, 230–247.
- Thrall, A.P., Billington, D.P., 2008. Bayonne bridge: the work of othmar ammann, master builder. *J. Bridge Eng.* 13 (6), 635–643.
- Ting, E.S., Murugamoorthy, E.C., Prasad, E.D.R., Rathnam, J., 2014. Review of footbridges in Singapore. In: *Footbridges 2014—Past, Present & Future*, London.
- Tuan, Y.F., 1974. *A Study of Environmental Perception, Attitudes, and Values*. Columbia University Press, New York.
- Tveit, P., 2008. *The Network Arch*. Available online at: <https://home.uia.no/pert/index.php/Home>. (Accessed 15 April 2021).
- Villa, F., 2001. Integrating modelling architecture: a declarative framework for multi-paradigm, multi-scale ecological modelling. *Ecol. Model.* 137 (1), 23–42.
- Waldheim, C., 2016. *Landscape as Urbanism: A General Theory*. Princeton University Press, Princeton.
- Walther, R., 1996. Engineers, architects and bridge design. *Struct. Eng. Int.* 6 (2), 77–79.
- Watanabe, Y., 2002. Miho Museum bridge, shigaraki, Japan. *Struct. Eng. Int.* 12 (4), 245–247.
- Worringer, W., 1997. *Abstraction and Empathy: A Contribution to the Psychology of Style*. Ivan R. Dee., Chicago.
- Khambazi, A., 2015. Thinking architecture through the traits of extroversion and introversion: territory as a question of environmental orientation and autonomy. *New Arch—Int. J. Contemp. Archit.* 2 (3), 11–24.
- Xiang, Z., Xu, W., Wang, C., Dong, Y., 2010. The construction technology of Chongqing Chaotianmen bridge. In: *Proceedings of ARCH’10—the 6th International Conference on Arch Bridges*, Fuzhou, pp. 803–811.
- Yu, K., Yu, H., Sing, Y., 2018. Restoring the mother river back to the city: puyangjiang river Corridor in Jinhua. *Landscape Architect. Front.* 6 (1), 64–76.
- Zhou, H., Leng, J., Zhou, M., Chun, Q., Hassanein, M.F., Zhong, W., 2018. China’s unique woven timber arch bridges. In: *Proc. of the Inst. of Civ. Eng.—Civ. Eng.*, vol. 171, pp. 115–120 (3).