

The Influence of Historic Landscape Principles on Contemporary Urban Green Infrastructure in Hot-Arid Climates: Insights from Chahar Bagh Boulevard in Isfahan, Iran

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Abstract

Ensuring thermal comfort in urban open spaces under hot-arid climatic conditions is a pressing priority for climate-responsive urban planning and the development of green infrastructure. High summer temperatures, intense solar radiation and limited water resources necessitate climate-adaptive approaches to the design of public space. This study examines the landscape-ecological and urban-planning characteristics of Chahar Bagh Boulevard, established in Isfahan during the Safavid period, and investigates how the integration of its historic spatial structure, tree plantations, water system, green spaces, pedestrian routes and public functions contributed to microclimatic comfort under hot-arid conditions.

The study is conceived as a conceptual, documentary-synthesis contribution rather than an empirical field study: it adopts a historical-documentary and comparative case-study approach. Historical sources, cartographic materials and published scholarly literature on the historical formation, spatial structure and microclimatic performance of Chahar Bagh were collected, systematised according to seven analytical indicators, and comparatively examined; no original fieldwork, on-site measurement or digital modelling was undertaken by the authors, and the microclimatic evidence discussed is drawn from previously published modelling studies.

The synthesis indicates that the climatic performance attributed to Chahar Bagh in the literature is explained less by individual landscape elements than by the integration of tree cover, water systems, pedestrian space and public activity into a coherent spatial-functional system. Rather than replicating the historical form of Chahar Bagh, adapting its principles of passive climatic responsiveness and landscape organisation to contemporary conditions is identified as the more defensible approach. These case-specific principles provide a starting point for further, locally grounded research on climate-responsive landscape strategies in hot-arid cities such as Samarkand.

Keywords: Chahar Bagh; Isfahan; hot-arid climate; green infrastructure; thermal comfort; historic landscape, Iran.

Introduction

In the twenty-first century, the adaptation of cities to climate change has become a priority area of research in landscape architecture and urban planning. The intensification of urbanisation, increasing urban density, the reduction of natural surfaces and the growing proportion of impervious hard surfaces are exacerbating outdoor thermal discomfort, particularly in hot-arid regions. Under such conditions, green infrastructure is increasingly regarded not merely as an aesthetic or recreational resource, but as an infrastructural system capable of regulating the urban microclimate and supporting environmental sustainability.

This research is based on the premise that historic cities that have come into being under hot-arid climatic conditions embody spatial and landscape solutions that have been tested and refined over long periods as forms of climatic adaptation. The historic urban landscape of Isfahan, and Chahar Bagh Boulevard in particular, is examined here as a case in which public, cultural, recreational and urban-planning functions have been integrated with tree cover, green spaces and water systems (Fig. 1).

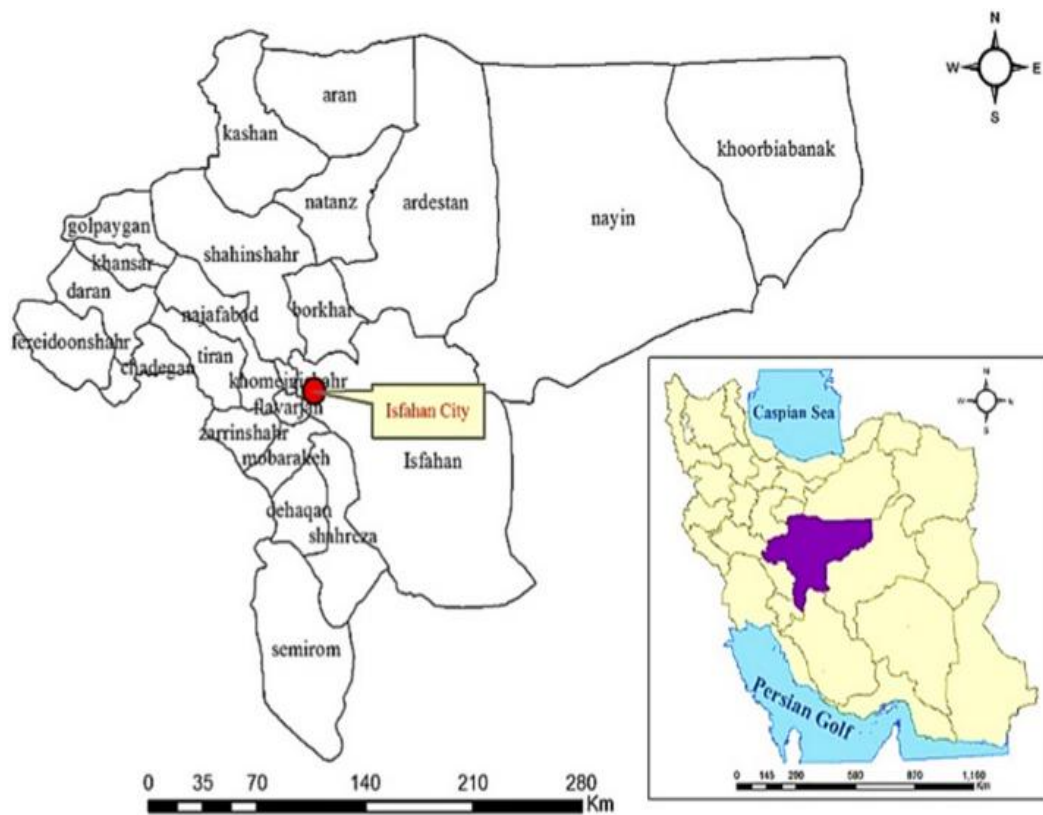


Fig. 1: Geographical location of Isfahan and the position of Chahar Bagh Boulevard within the urban structure.

Source: Authors, based on cartographic materials cited in the text.

Mosavi and colleagues emphasise that the use of water and vegetation in the historic streets of Isfahan has constituted an important component of long-established traditions of climatic adaptation, and that this approach has contributed to improving the environmental and microclimatic conditions of the urban environment through the interrelationship between water, vegetation and spatial structure (Habibi et al., 2020). From this perspective, the climatic performance of historic landscapes needs to be assessed not merely in terms of the presence of individual elements, but through the manner in which these elements are integrated into a coherent spatial-functional system.

Chahar Bagh has developed during the Safavid period, from the late sixteenth to the early seventeenth century, as one of the principal compositional and urban axes contributing to the formation of the new urban structure of Isfahan. Ahmadi (2016) identifies it as an important component of the reorganisation of Isfahan under Shah Abbas I, with the boulevard developing in an integrated spatial relationship with the gardens and urban spaces situated along its course.

Studying Chahar Bagh solely as a historic architectural monument or traditional boulevard, however, does not fully reveal its potential relevance to contemporary urban planning.

Although existing studies have examined the historical development, architectural and compositional characteristics, and role of Chahar Bagh in Safavid urban planning (Ahmadi, 2016; Blake, 1999; Canby, 2009), the microclimatic performance of the interrelationships between tree cover, water systems, green spaces and pedestrian movement under hot-arid climatic conditions has not yet been examined in an integrated manner, nor has it been synthesised with the social and pedestrian dimensions of the boulevard's contemporary use. This research gap highlights the need to examine Chahar Bagh not as an assemblage of individual historic landscape elements, but as a coherent spatial-ecological system that may inform climatic adaptation. On this basis, the central research question is formulated as follows: what scientific and practical insights do the historic landscape-design principles of Chahar Bagh Boulevard offer for the development of contemporary green infrastructure in hot-arid climatic conditions?

The aim of this study is to synthesise the existing historical, cartographic and scholarly evidence on the historical development, spatial-landscape organisation, and microclimatic and social functions of Chahar Bagh Boulevard, and to recognize, on this basis, landscape and urban-planning principles that may be relevant to hot-arid cities such as Samarkand. The specific objectives are as follows.

1. To trace the historical-morphological formation of Chahar Bagh within Safavid Isfahan;
2. To characterise its spatial-compositional, phytomorphological and hydrological structure on the basis of published sources;
- 3 To synthesise published evidence on the microclimatic and pedestrian-social performance of these components; and
- 4 To distil case-specific landscape principles capable of informing, rather than being generalised to, the design of contemporary green infrastructure in comparable climatic contexts.

Theoretical Framework

This study draws on three complementary theoretical strands. The first concerns the reading of urban space as a structured composition of interrelated parts. Lynch (1960) proposes that the legibility of urban space can be analysed through the interaction of paths, edges, districts, nodes and landmarks, arguing that a coherent urban form is one in which movement, boundary and focal points are organised into a perceptible hierarchy. This study adapts Lynch's (1960) vocabulary, in the form of an axis-edge-node reading, to describe the spatial-compositional structure of Chahar Bagh, in which the boulevard constitutes the principal axis, tree plantations and gardens define spatial edges, and bridges, pools and intersections form functional nodes.

The second strand concerns the concept of green infrastructure itself. Benedict and McMahon (2006) define green infrastructure as an interconnected network of natural and semi-natural landscape elements that is planned and managed for the ecosystem services it provides, arguing that green space performs an infrastructural function comparable to that of engineered systems, rather than a merely decorative one. This study adopts Benedict and McMahon's (2006) understanding of green infrastructure as an analytical lens through which the historic tree, water and pedestrian systems of Chahar Bagh are interpreted.

The third strand concerns the relationship between historic urban landscapes and contemporary planning. UNESCO's (2011) Recommendation on the Historic Urban Landscape proposes that historic urban areas should be understood as layered, dynamic environments whose heritage value lies not only in their physical fabric, but in the underlying spatial and environmental principles that can continue to inform present-day urban management. Following this approach, the historic landscape of Chahar Bagh is treated in this study not as a form to be replicated, but as a source of operational principles to be critically adapted to contemporary hot-arid urban conditions.

Review of Literature

Several strands of research on the Iranian and Isfahani context bear directly on Chahar Bagh. For example, Ahmadi (2016) traces the genealogy of the Chahar Bagh Avenue, arguing that its design synthesised pre-Islamic and Islamic garden-traditions and tracing its subsequent physical degeneration from the Safavid into the Qajar and Pahlavi periods. He provides the historical-morphological foundation on which the present study's account of the boulevard's formation is based. Similarly, Habibi et al. (2020) have done a diachronic, software-assisted comparison of three scenarios of Chahar Bagh Street: its Safavid-era configuration, its present condition, and a hypothetical condition with all the natural elements removed. Using the Predicted Mean Vote (PMV) model, they have found that the comfort-providing area under the historical configuration has been seven to seventeen times larger than under the other two scenarios, and that the contemporary condition has remained 1.5°C cooler than the degraded scenario. This is, to date, the most directly relevant quantitative evidence available on the microclimatic performance of the boulevard, and the present study relies on it rather than on any original modelling.

Complementing this environmental focus, Emami (2024) offers a detailed reconstruction of the sensory and social experience of the Chaharbagh promenade in Safavid Isfahan, drawing on Persian-language poetic descriptions and European travel accounts to show how the avenue functioned as a choreographed public and ceremonial space rather than a simple thoroughfare. HaghighatBin, Saghafi Moghaddam and Nijhuis (2024) have examined the more recent history of the street, arguing that inconsistent urban-renewal policies have weakened role of Chahar Bagh as a site of collective memory, and that conservation and regeneration should be pursued as complementary rather than separate processes.

Taken together, these studies indicate that historical and environmental characteristics of Chahar Bagh have been examined from complementary but largely separate perspectives: as an architectural-historical genealogy (Ahmadi, 2016), as a quantifiable microclimatic system (Habibi et al., 2020), as a sensory-social space (Emami, 2024), and as a contested site of memory and renewal (HaghighatBin et al., 2024). What remains comparatively underdeveloped, and what the present study seeks to address through a documentary synthesis of these existing strands, is an integrated reading of how the boulevard's spatial, ecological and social components interacted as a single system, and what case-specific principles this integration might offer for green-infrastructure in other hot-arid historic cities.

Research Methodology

The research object is the historic Chahar Bagh Boulevard in Isfahan, established during the Safavid period. This is thus a cases study. Interpreting Chahar Bagh merely as a conventional transport route does not fully reflect its historic and ecological character: it has evolved as an urban-landscape structure integrating the boulevard, gardens, tree plantations, water elements, architectural complexes and public spaces into a unified spatial-compositional system (Blake, 1999; Ahmadi, 2016).

This study adopts a historical-documentary and comparative case-study approach; it is a desk-based synthesis of published sources, not an empirical field or laboratory study. No site visit, survey, interview or original microclimatic measurement or simulation was undertaken by the authors. This limitation follows directly from the study design: the aim is to synthesise and interpret the existing historical and scholarly record on Chahar Bagh, not to generate new primary environmental data.

The source base comprised three categories of materials, each identified through targeted searching of academic databases and library catalogues rather than original archival research:

- (i) Published historical-architectural studies of Chahar Bagh and Safavid Isfahan (Savory, 1990; Haneda and Matthee, 2006; Blake, 1999; Canby, 2009; Ahmadi, 2016; Golombek, 1990; Emami, 2024);
- (ii) Published quantitative and qualitative studies of the boulevard's microclimatic and social performance (Habibi et al., 2020; HaghighatBin et al., 2024); and

- (iii) Secondary compilations of historical cartographic material and European travellers' accounts as reproduced and discussed within the above sources, principally Blake (1999) and Ferrier (1996), rather than original manuscripts consulted directly by the authors. These materials were compared for consistency with one another and organised according to seven analytical indicators (Table 1), which structure the synthesis presented in the Findings section below.

Table 1: Analytical Model of the Study

Source: Authors.

No	Analytical Framework of the Study	Analytical Content
1	Historical-Morphological Development	The role of Chahar Bagh in the Safavid urban-planning system, its stages of formation, and its function in urban development
2	Spatial-Compositional Structure	Axial, hierarchical and functional relationships between the boulevard, gardens, water elements, architectural features and the urban fabric
3	Phytomorphological System	Composition of tree and plant species, spatial arrangement, alignment, density and characteristics of shade-providing spaces
4	Hydrological-Landscape System	The role of channels, pools and irrigation networks in landscape composition, environmental sustainability and microclimate formation
5	Microclimatic Comfort	The interrelationship between shading, evaporation, air temperature and humidity, and thermal comfort within pedestrian spaces, as reported in published modelling studies
6	Pedestrian and Social Space	Functional organisation of pedestrian movement, walking routes, recreational activities, rest areas and open public spaces
7	Contemporary Adaptive Integration	Integration of historic landscape principles into contemporary green infrastructure, climate-responsive urban planning and sustainable public spaces

These indicators provide a unified analytical framework for systematically synthesising the published evidence on Chahar Bagh, from its historical formation to its ecological and microclimatic functions and its potential relevance for contemporary urban planning contexts. To make explicit which claim in the Findings section rests on which source - a correspondence the editorial review specifically requested - Table 2 maps each analytical indicator onto the specific source(s) from which the corresponding evidence is drawn.

Table 2: Correspondence Between Analytical Indicators and Source Material

Source: Authors.

Analytical Indicator	Primary Source(s) of Evidence	Type of Evidence
1. Historical-Morphological Development	Haneda and Matthee (2006); Ahmadi (2016)	Historical-architectural scholarship
2. Spatial-Compositional Structure	Ahmadi (2016); Haneda and Matthee (2006); Ardalan and Bakhtiar (1973)	Historical scholarship; interpretive framework after Lynch (1960)
3. Phytomorphological System	Canby (2009); Ahmadi (2016); Savory (1990); Hobhouse (2002)	Historical-architectural and garden-history scholarship
4. Hydrological-Landscape System	Blake (1999); Haneda and Matthee (2006)	Historical-architectural scholarship
5. Microclimatic Comfort	Habibi et al. (2020)	Published quantitative modelling (PMV); sole source, not independently verified by the present authors
6. Pedestrian and Social Space	Emami (2024); HaghighatBin et al. (2024)	Historical-sensory scholarship; contemporary social-urban research
7. Contemporary Adaptive Integration	Benedict and McMahon (2006); UNESCO (2011)	Theoretical framework applied by the present authors to synthesise 1-6 above

Findings: A Synthesis of Chahar Bagh Based on Seven Indicators

Historical-Morphological Development

According to the sources reviewed, the historical-morphological development of Chahar Bagh has been closely associated with the re-organisation of Isfahan as the Safavid capital and the city's subsequent expansion along new urban axes. Under Shah Abbas I, a new political, administrative and commercial centre has been established, bringing Naqsh-e Jahan Square, Royal palace complexes, bazaars, newly developed residential quarters and gardens into an integrated urban-planning system. Chahar Bagh has been conceived as a key component of this transformation, functioning as a principal spatial axis connecting the newly developed urban districts with the Zayandeh Rud valley and the gardens to the South (Haneda and Matthee, 2006; Ahmadi, 2016). Indeed, literature indicates that the establishment of Chahar Bagh has been associated with the designation of Isfahan's as the Safavid capital in 1597-1598, while its planning has been incorporated into the new urban development programme around 1602, with the boulevard reaching a maximum width of approximately 48 metres and extending southwards towards the Allahverdi Khan Bridge across the Zayandeh Rud (Ahmadi, 2016).

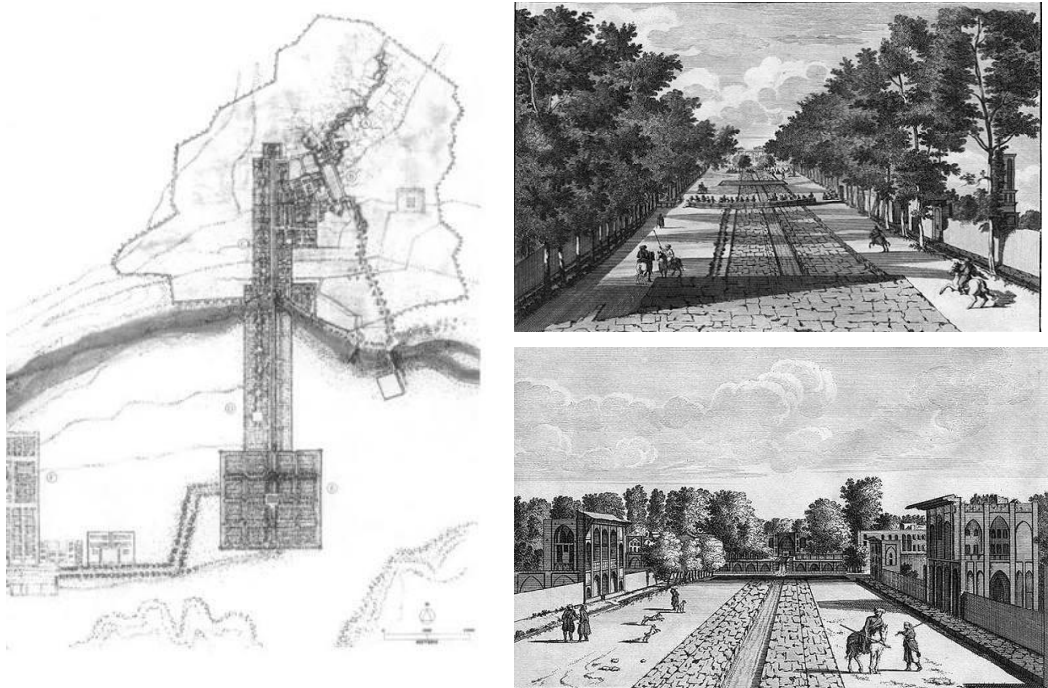


Fig. 2: The role of Chahar Bagh in the historic urban and garden system during the Safavid period.
Source: Ferrier (1996: 61); illustration attributed to Sir John Chardin, as reproduced in Ferrier (1996).

The establishment of gardens on both sides of Chahar Bagh indicates that the boulevard functioned not merely as a communication route, but as an urban-planning element shaping the relationship between the garden and the city. Within the Safavid urban-planning concept, extensive garden areas have been incorporated into the overall plan of the new capital, with the gardens arranged along Chahar Bagh spatially connected to major landscape complexes such as Naqsh-e Jahan and Hasht Behesht (Golombek, 1990; Canby, 2009). This historic configuration has defined the morphological character of Chahar Bagh. Its principal axis has connected the urban centre with the southern landscape areas, while the adjoining gardens have enriched the urban fabric with ecological and recreational components (Fig. 2). Urban development has been thus achieved not solely through the expansion of the built environment, but through the parallel formation of built space and landscape.

Spatial-Compositional Structure

Following path-edge-node theory of Lynch (1960), reading urban space, the spatial-compositional structure of Chahar Bagh can be understood as based on a hierarchical relationship between its longitudinal axis, rows of trees, water elements, gardens and architectural features. Historical accounts describe the boulevard as broad and rectilinear, with gardens arranged along its sides and water channels connecting different parts of the landscape (Ahmadi, 2016; Haneda and Matthee, 2006).

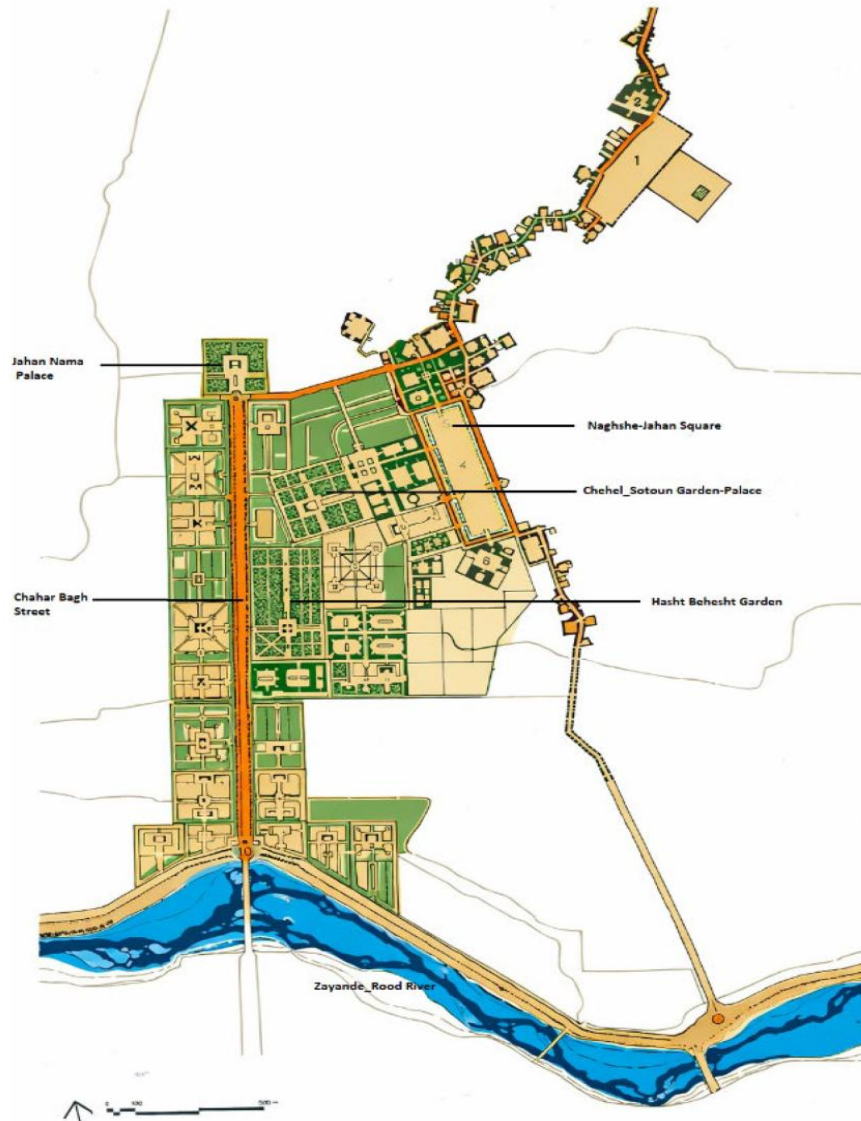


Fig. 3: The city-scale spatial-compositional structure of Chahar Bagh: the principal axis and its relationship with the gardens and the Zayandeh Rud.

Source: Redrawn by the authors after Ardalan and Bakhtiar (1973).

In this reading, the principal boulevard constitutes the urban axis; tree plantations and gardens define the spatial edges; while the bridges, the pools, the palaces and the intersections form functional and visual nodes. Such a hierarchy is understood to have organised the movement, visual perception and opportunities for pause sequentially within the linear spatial structure. The connection of Chahar Bagh with the Zayandeh Rud and the Si-o-se-pol further extended its spatial structure at the city scale: the river functioned as a natural landscape axis, while the boulevard operated as an artificial urban axis, and their intersection strengthened the integration of natural and anthropogenic space within the emerging urban form of Isfahan (Haneda and Matthee, 2006).

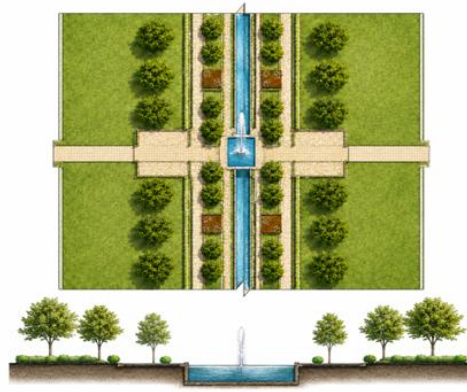


Fig. 4: Phytomorphological and spatial structure of Chahar Bagh: tree rows, planting rhythm, water elements and shaded zones.

Source: Authors' analytical diagram, based on the sources discussed in the text.

Phytomorphological System

The phytomorphological system of Chahar Bagh is identified in the literature as one of the principal factors defining its historic landscape character. During the Safavid period, the establishment of extensive gardens on both sides of the boulevard and the incorporation of tree plantations into its spatial composition are reported to have provided the urban environment with a continuous green structure distinguishing it from the surrounding built fabric (Canby, 2009; Ahmadi, 2016). Historical studies indicate that plane trees, cypresses and other locally well-adapted species have been used in the gardens of Isfahan and along Chahar Bagh, with the linear arrangement of trees corresponding to the geometric principles of Persian garden design (Savory, 1990; Hobhouse, 2002).

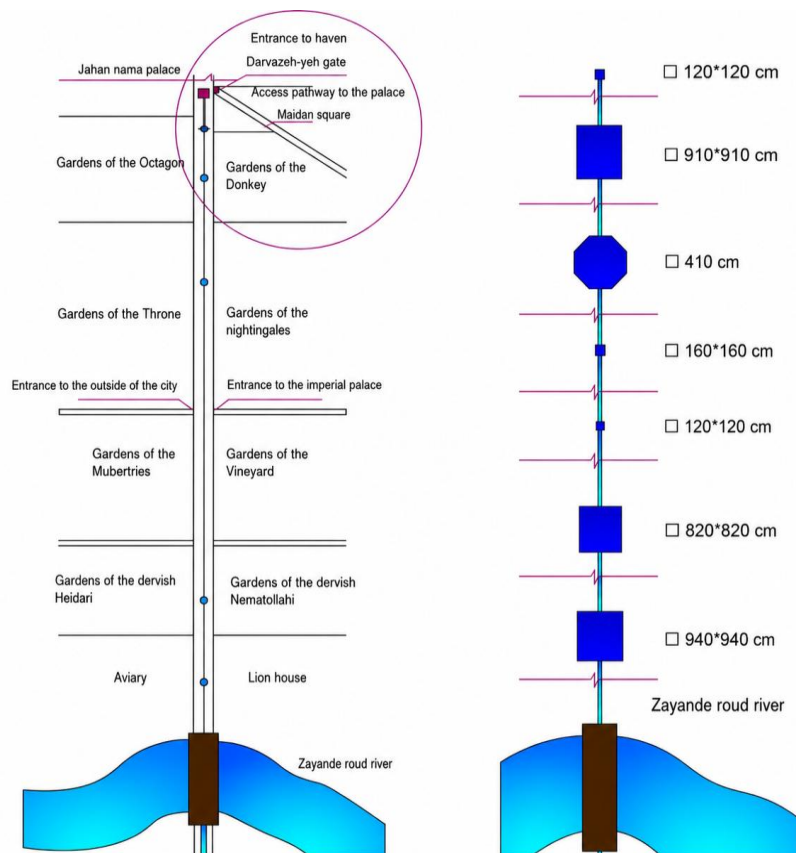


Fig. 5: Heptad pools' dimensions and the gardens around each pool, based on Chardin's descriptions.

Source: Ahmadi (2015), as cited in Ahmadi (2016).

From this perspective, the reviewed sources suggest that vegetation in Chahar Bagh has performed a functional role broader than that of conventional decorative planting: trees simultaneously has served functions of spatial definition, orientation, shading and microclimatic moderation, a multifunctional character that in several respects corresponds to the contemporary concept of green infrastructure proposed by Benedict and McMahon (2006).

Hydrological-Landscape System

The use of water as a central and orientating element is identified as one of the principal factors shaping the spatial-compositional structure of the Chahar Bagh landscape. During the Safavid period, the water channel arranged along the central axis of the boulevard is reported to have reinforced its linear compositional direction, with pools, water-collection points and small cascades positioned along the channel creating rhythmic and visual nodes within the landscape (Blake, 1999; Haneda and Matthee, 2006).



Fig. 6: The current landscape-spatial condition of Chahar Bagh.

Source: Wikipedia (n.d.), Chaharbagh, Isfahan.

The function of the water system has extended beyond its aesthetic and compositional effects: it has formed an integral component of the hydraulic infrastructure sustaining the gardens and landscape areas surrounding Chahar Bagh, with water distributed through channels connected to the Zayandeh Rud enabling the irrigation of gardens, tree plantations and cultivated areas (Blake, 1999). This characteristic allows Chahar Bagh to be interpreted not simply as a 'water boulevard', but as a historic blue-infrastructure model in which water fulfilled three interrelated functional roles: irrigation and water supply; spatial and compositional organisation; and, according to the modelling evidence discussed below, microclimatic regulation.

Microclimatic Comfort

The most direct evidence on the microclimatic performance of Chahar Bagh comes from Habibi et al. (2020), who modelled the historic and contemporary configurations of the boulevard based on its water and vegetation components and assessed the influence of these natural elements on environmental comfort (Fig. 7). Their findings demonstrate that the presence of water channels and green cover significantly affects air temperature, relative humidity and thermal comfort indices, with the comfort-providing area under the Safavid-era configuration seven to seventeen times larger than under the contemporary and degraded scenarios, and the contemporary condition remaining approximately 1.5°C cooler than the degraded scenario (Habibi et al., 2020) (Fig. 8).

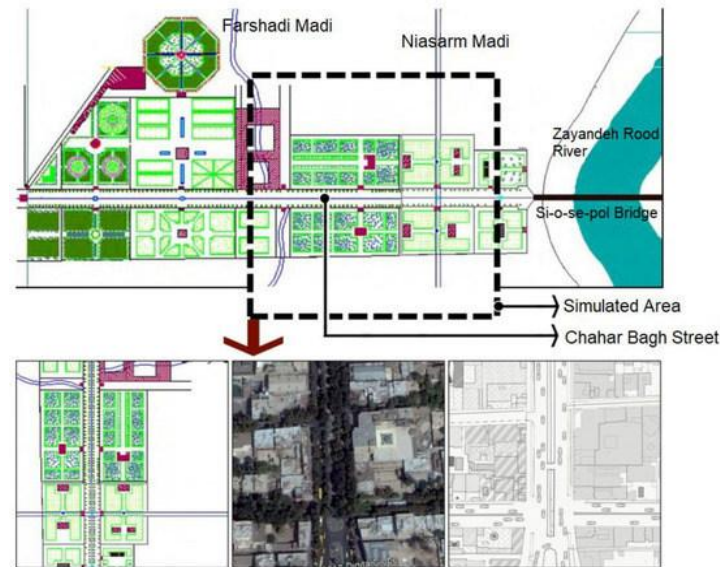


Fig. 7: Relationship between the historic geometry of Chahar Bagh and the contemporary study area.

Source: Adapted by the authors from Habibi et al. (2020).

These findings, reported by Habibi et al. (2020), indicate that the microclimatic performance of Chahar Bagh is not attributable to any single landscape element, but results from the combined effect of interconnected ecological and spatial components, which the present study interprets through the interaction of shade, water, vegetation and spatial configuration within the historic landscape system. On this reading, trees and dense vegetation are understood to have reduced direct exposure to solar radiation and have created shaded pedestrian micro-zones, while evapotranspiration from vegetation and evaporation from water surfaces are understood to have moderated heat exchange, together contributing to overall microclimatic amelioration (Habibi et al., 2020).

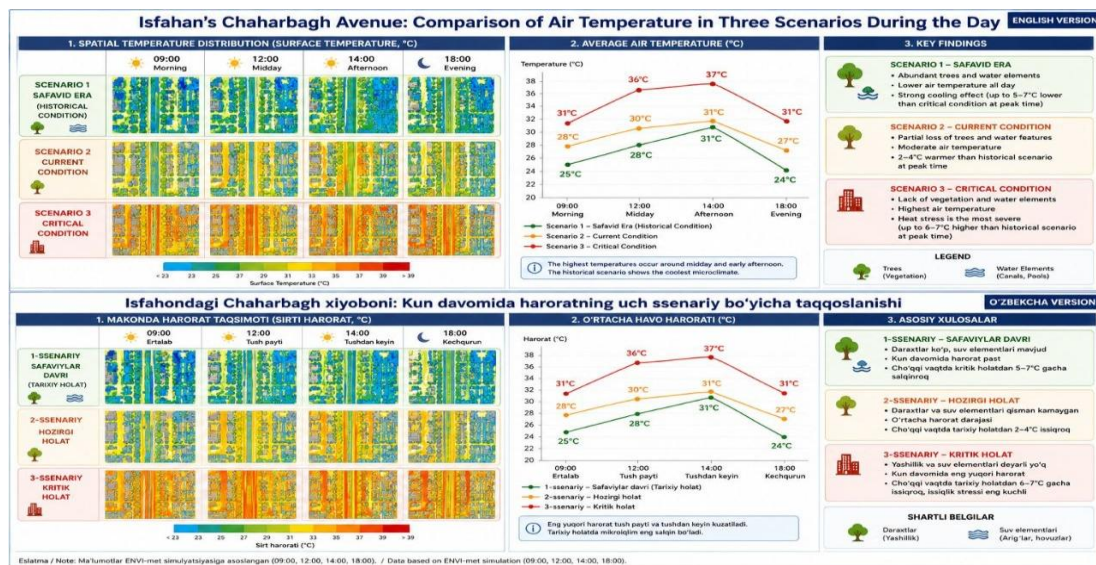


Fig. 8: Comparative diurnal temperature distribution across three scenarios along Chahar Bagh Boulevard.

Source: Habibi et al. (2020).

It should be emphasized that this microclimatic evidence is secondary: the present study did not conduct its own modelling, measurement or simulation, and the findings summarized here reflect the published results of Habibi et al. (2020) rather than original data generated by the authors.

Pedestrian and Social Space

The pedestrian environment of Chahar Bagh is described in the literature as having been directly associated with its natural components: rows of trees have created shaded routes, while water elements have enhanced the visual and microclimatic qualities of the spaces, and the gardens, palaces and the bridges have formed a series of functional nodes along the pedestrian routes (Emami, 2024). On this basis, the pedestrian environment can be understood not simply as a network of paths facilitating movement, but as a public realm integrating movement, visual experience, recreation and social interactions.

Interestingly, HaghighatBin, Saghafi Moghaddam and Nijhuis (2024) examine the contemporary condition of Chahar Bagh as a public space, arguing that its historic and social significance has changed over time under the influence of successive urban-renewal policies, and that the declining significance of the boulevard as a site of collective memory and historic public life should be addressed through conservation and regeneration pursued as complementary, rather than separate, processes.

This finding suggests that the reorganisation of historic pedestrian spaces cannot rely solely on transport or landscape indicators: the pedestrian environment needs to be considered in conjunction with social memory, cultural identity, recreation and everyday activities, and, given the economic functions associated with the contemporary pedestrianisation of Chahar Bagh, the balance between social, cultural and economic functions is arguably a more appropriate criterion than the mere creation of traffic-free space (HaghighatBin et al., 2024).

Contemporary Adaptive Integration

Drawing on the Historic Urban Landscape approach advocated by UNESCO (2011), the reviewed evidence suggests that integrating the historic principles of Chahar Bagh into contemporary green infrastructure requires adapting its ecological and spatial operating mechanisms to present-day conditions, rather than reproducing its historic form literally. On this basis, four directions of adaptive integration can be distilled from the synthesis above.

1. This is the development of continuous green corridors: in the historic structure of Chahar Bagh, rows of trees and gardens created a continuous green environment along the boulevard, a principle that in contemporary urban contexts can be developed by integrating street trees, green pedestrian routes, ecological corridors and public gardens into a coherent network functioning as infrastructure rather than mere ornament (Benedict and McMahon, 2006).
2. The second is the integration of blue-green infrastructure: in the historic system of Chahar Bagh, water and vegetation functioned as complementary components, a principle that can be reinterpreted in contemporary planning through the integrated design of water-efficient irrigation, rainwater management, water reuse, ecological drainage and green space.
3. The third is climate-responsive pedestrian infrastructure: the modelling evidence reviewed above (Habibi et al., 2020) provides quantitative support for the proposition that combined tree shade and water elements improved the thermal quality of pedestrian space in historic Chahar Bagh, a relationship that can inform the design of shaded, climate-responsive pedestrian routes in contemporary hot-arid cities.
4. The fourth is the balance between historical identity and contemporary use: following HaghighatBin et al. (2024), conservation and regeneration of historic boulevards are best pursued as complementary rather than separate processes, with landscape characteristics, collective memory and patterns of social use considered in an integrated manner.

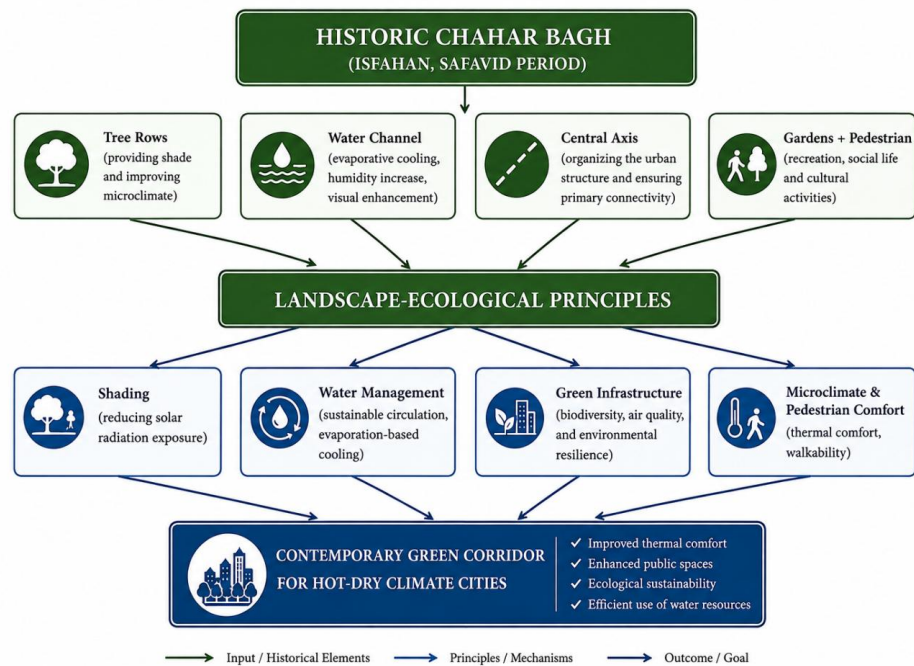


Fig. 9: Adaptive integration of the historic principles of Chahar Bagh into contemporary green infrastructure in hot-arid cities: authors' conceptual model.

Source: Authors.

Discussion

The synthesis based on seven indicators suggests that the historical performance attributed to Chahar Bagh in the reviewed literature has been determined not by the presence of individual landscape components, but by their interactions within an integrated spatial-functional system. This reading allows Chahar Bagh to be interpreted not simply as a landscaped boulevard, but as a complex historic urban landscape integrating urban structure, landscape morphology, water management, microclimatic regulation and public activities (Savory, 1990; Habibi et al., 2020; HaghighatBin et al., 2024).

Historical-morphological analysis of the reviewed sources indicates that Chahar Bagh has been established during the Safavid period as part of the broader urban-development strategy of Isfahan's with the major urban transformations associated with the city's designation as the Safavid capital transforming the boulevard into an important urban axis connecting new political, social and recreational spaces (Haneda and Matthee, 2006; Ahmadi, 2016). According to Savory (1990), the boulevard has been oriented towards the Zayandeh Rud and the Allahverdi Khan Bridge, with its southern extension connected to the gardens of the Hazarjarib area. The spatial structure of Chahar Bagh therefore cannot be adequately understood as merely a linear street configuration; it has functioned as a landscape-urban corridor connecting the city centre, palace-garden complexes, water systems, bridges and recreational areas.

The spatial-compositional evidence further suggests that the internal organisation of this urban axis has not been arbitrary. The arrangement of the tree rows, the central water channel, pedestrian paths, gardens and architectural elements is understood, following the city framework advocated by Lynch (1960), to have reinforced the spatial direction of the boulevard and has organised movements through a sequence of visual and functional nodes, transforming the pedestrian route from a mere means of movement between two points into an environment of sequential experience and activities.

Phyto-morphological and hydrological evidence further clarifies the ecological functioning of this spatial system. While tree cover is reported to have improved the thermal quality of the pedestrian environment by reducing direct solar radiation creating shaded micro-zones, evapotranspiration from vegetation and evaporation from water surfaces are reported to have contributed to the regulation of heat exchange (Habibi et al., 2020). The role of water has

therefore not been limited to decorative or visual functions, but has also been associated with irrigation, the maintenance of garden environments, and the moderation of microclimatic conditions. Accordingly, the historical ecological performance of Chahar Bagh can be interpreted through the triad of the green component, the blue component and the spatial organisation.

This interpretation is further supported by the microclimatic modelling of Habibi et al. (2020), which has compared the Safavid-era configuration of Chahar Bagh with its contemporary condition and a scenario in which natural elements had been removed, demonstrating considerably more favourable thermal comfort conditions under the historical configuration. The contribution of this study is that it demonstrates the influence of natural components not only qualitatively but also quantitatively, through modelling; the present synthesis relies on this quantitative evidence rather than on any original measurement. At the same time, interpreting microclimatic comfort solely as an ecological outcome does not fully explain the social function of Chahar Bagh: a thermally comfortable pedestrian environment is understood to create favourable conditions for staying, walking, meeting and social activities, and ecological components should therefore be understood not as passive decorative features of public spaces, but as factors associated with the intensity of their use (HaghighatBin et al., 2024).

From this perspective, the reviewed evidence allows the following functional chain to be proposed for Chahar Bagh: urban framework leads to landscape-ecological organisation, which leads to microclimatic comfort, which leads to pedestrian use, and then it leads to social activities. The significance of this chain is that ecological and social performances are not treated as separate dimensions: the urban structure determines the spatial distribution of natural components. The natural components regulate the microclimate, microclimatic conditions affect the usability of pedestrian spaces, and the pedestrian activities support the social life of the public space.

When transferring this historical model to contemporary urban conditions, it is important to distinguish between formal reconstructions and functional adaptations. Replicating the historical composition of Chahar Bagh exactly may not always be appropriate given the density, transport systems, water resources, environmental requirements and patterns of use characteristic of contemporary cities. Following the Historic Urban Landscape approach of UNESCO (2011), its contemporary relevance is understood to lie not in the historical form itself, but in the operational principles underlying that form: contemporary adaptation should answer the question of how Chahar Bagh functioned, rather than simply what it looks like.

This applies, first, to the design of green corridors: the primary function of the historical tree rows has not been limited to shaping the visual character of the boulevard, but also has contributed to shading, orientation, the regulation of pedestrian movements and the continuity of the green environment, a principle that under contemporary conditions can be reinterpreted by integrating street trees, green pedestrian paths, public gardens and ecological corridors into a coherent network functioning as thermal-regulation and ecological-connectivity infrastructure, rather than aesthetic embellishments (Benedict and McMahon, 2006).

It applies, second, to the hydrological system: in historical Chahar Bagh. The water channels are reported to have contributed to irrigation, landscape maintenance and the ecological quality of the spaces (Blake, 1999; Habibi et al., 2020). In contemporary hot-arid urban environments, this principle can be continued through water-efficient irrigation, rainwater harvesting, water reuse, permeable surfaces, ecological drainage and blue-green infrastructure adapted to local water balances - that is, not the physical appearance of the historical hydrological system, but its function of resource management and microclimatic support.

It applies, third, to the vegetation system, which likewise requires an adaptive rather than a purely decorative approach. Rather than reproducing historical tree rows merely as ornamental landscaping, they can be designed as multifunctional green structures that regulate solar radiation, protect pedestrian routes, support biodiversity and connect public spaces, with the value of tree cover assessed not solely by its quantity, but by indicators such as shading

performance, spatial continuity, water requirements and influence on the pedestrian environment.

A further important aspect of the Chahar Bagh case, following HaghighatBin et al. (2024), is the need to integrate ecological adaptation with cultural heritage: in contemporary regeneration processes, increasing thermal comfort or expanding green spaces alone cannot address all the challenges associated with historical public spaces, and ecological regeneration therefore needs to be coordinated with historical identity, collective memory and existing patterns of social use. This shifts the contemporary relevance of the Chahar Bagh case beyond the scope of a merely 'green' or 'climate-responsive' project towards the broader framework of cultural-ecological urbanism proposed by UNESCO (2011).

On this basis, Chahar Bagh can be understood not as a ready-made compositional model for contemporary green infrastructure, but as a historical urban paradigm operating at several interconnected levels: as a spatial axis connecting different parts of the urban fabric; as an ecological system based on water and vegetation; as a thermally comfortable pedestrian environment; and as a setting integrating social and cultural activities. The principal implication of this synthesis is the need to interpret the historical experience of Chahar Bagh in terms of continuing its operational principles rather than preserving its form, understanding the historical landscape not as a museumised artefact, but as a source of case-specific insight into hot-arid climatic adaptation.

As emphasised throughout this Discussion, this insight is drawn entirely from published secondary sources. It has not been verified against original archival material, on-site surveys or independent modelling by the present authors, and any application of these principles to another city needs to be evaluated in relation to that city's own climate, water balance, plant resources, urban morphology and cultural context, and, ideally, supported by locally collected primary data. This is indeed a weakness of this study, although its strength lies in the fact that it is for the first time that this issue is looked at from this perspective.

Conclusion

This study has synthesised published historical, cartographic and scholarly evidence to interpret Chahar Bagh Boulevard not merely as an individual architectural feature of Safavid-era Isfahan, but as a multifunctional historic urban landscape in which urban structure, landscape, water, vegetation, microclimate and public activities are represented in the literature as an integrated system. The synthesis, organised around seven analytical indicators, indicates that the historical performance of the boulevard reported in the reviewed sources was determined not by the presence of individual elements, but by their spatial and functional interrelationships.

On the basis of this synthesis, and drawing directly on the case of Chahar Bagh, five landscape and urban-planning principles are identified:

1. **Continuous green corridors** - tree plantations and gardens organised as a continuous, connected green structure along a primary urban axis, rather than as isolated plantings, functioning as thermal-regulation infrastructure.
2. **Blue-green infrastructure integration** - water channels, pools and irrigation systems planned jointly with vegetation, so that irrigation, spatial organisation and microclimatic regulation are achieved through a single, coordinated system rather than through separate elements.
3. **Climate-responsive pedestrian infrastructure** - the combined use of shade, water and spatial configuration to create pedestrian routes and public spaces with measurably improved thermal comfort, as demonstrated for the historical case by Habibi et al. (2020).
4. **Balance between historical identity and contemporary use** - conservation and regeneration of historic boulevards pursued as complementary rather than separate processes, with collective memory and social use considered alongside environmental performance (HaghighatBin et al., 2024).

5. Preservation of landscape multifunctionality - trees, water, pedestrian pathways and public space designed and managed as interconnected components of a single system, rather than as independent design elements.

It is emphasized that these five principles are specific to the case of Chahar Bagh Boulevard, as documented in the sources reviewed here, and are not presented as a generalised model for hot-arid historic landscapes as a class. Their relevance to other cities, including Samarkand, is a matter for separate, locally grounded investigation - involving primary data collection, on-site survey and, where appropriate, original microclimatic measurement or modelling - rather than direct transfer.

Within this limit, the Chahar Bagh case indicates that the design of high-quality public landscapes in hot-arid cities benefits from treating ecological, spatial and social factors as an integrated system: in this sense, the most significant implication of the Chahar Bagh case for contemporary urban planning lies not in its historical form itself, but in the landscape-urban principle of integrating urban space, natural process and human activity within a single, coherent functional system.

Declarations

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Ethical Practice: This research followed accepted ethical practices. It is a documentary, desk-based synthesis of previously published historical, cartographic and scholarly sources; it did not involve human participants, fieldwork, interviews or the collection of any personal data.

Availability of Data: This study does not report original primary data. All evidence discussed is drawn from the published sources cited in the References below, each of which is publicly accessible through the identifiers (DOI or publisher) provided.

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