10.22034/4.10.3 *Revitalization School*, *4*(10), 26-33, 2026

Original Research Article

Proportions in Infill Design, The Connecting Criterion Between New and Old Structures*

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ARTICLE INFO

Received: 06 March 2026
Revised: 19 April 2026
Accepted: 19 May 2026
Online available: 22 May 2026

Keywords
Infill, Scale, Proportions, Old buildings, New structures

ABSTRACT

To date, at various levels, infill strategies have primarily addressed proportions in larger-scales and historical contexts; however, the proportional relationship between a new adjacent building and an individual historic structure has remained overlooked. In other words, new structures have lost their proportional coexistence with the values of older buildings. Within the infill approach, any new structure inevitably affects the surrounding valuable buildings and perceives itself not in confrontation with, but in meaningful dialogue with the older structure. Neglecting this issue leads to visual disharmony in the overall urban image and gradually diminishes the identity of the valuable building.

The aim of this research is to understand the new architectural structure compatible with existing structures. and seeks to answer the question: which dimension of proportion is more influential in infill design? To this end, after reviewing the research background and literature, the component of proportions was extracted from the set of scales in infill strategies and investigated across four general criteria: “physical proportions”, “functional proportions”, “human proportions”, and “aesthetic proportions”. Then, using multi criteria decision making methods (AHP and TOPSIS), data obtained from 15 questionnaires completed by specialists, experts, and professors of architecture and restoration were analyzed. Through a descriptive–analytical approach, the degree of influence of proportional dimensions in infill design was determined.

Ultimately, “functional proportions”, with a final weight of (0.131), were identified as the most effective design strategy for new structures adjacent to heritage buildings (case study: Rasht Flour Milling Factory). From the perspective of this study, the alignment between the function and program of the new building and that of the heritage structure plays a crucial role in the success of an infill design.

* This article is extracted from “Ava Khadem”’s master’s thesis entitled “Designing a boutique hotel according to the principles and methods of infill architecture in Rasht” that is being done under supervision of Mr. “Seyed Mohammadreza Faroughi” at the Faculty of Architecture and Art, University of Guilan.

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Introduction

One of the primary challenges in new constructions is disharmony between recent additions and the existing valuable structures. Neglecting this issue leads to irreversible consequences such as reduced efficiency in adjacent buildings, the accelerated deterioration of the heritage structure, a declining tendency to inhabit or interact with older buildings, the emergence of incoherent and visually discordant spaces within the city, and the weakening of the valuable building's identity. The Rasht Flour Milling¬ Factory is among the cases that suffer from such neglect. Infill architecture is aligned with this aim. Constructing new buildings within historical contexts in order to sustain the physical, social, and economic vitality of the context and to improve living standards, social welfare, and contemporary needs is both necessary and undeniable. However, if this necessity is approached without an appropriate and informed methodology, it can lead to damage in the overall visual character of historic cities (Iman talab et al, 2017, 8). In this regard, preserving and adapting old buildings while acknowledging their historical and cultural significance alongside removing portions that reduce functional efficiency and flexibility, and constructing new elements that generate usable and compatible spaces, are among the principal strategies for the development and protection of historic structures and contexts (Shah Teimori & Mazaherian, 2012, 30). These strategies reflect a fundamental principle: adaptation and enhancement of functionality must never come at the cost of losing the identity of the valuable structure. Even though these discussions arise primarily within historical contexts, their underlying logic reveals that preserving authenticity while improving usability is a total rule in architectural design. New structures within any city must maintain the defining qualities of their surrounding environment and built context, enrich and elevate their visual presence, and ensure meaningful continuity between the old and the new.

Proportions serve as a component for achieving qualitative and visual coherence. Proportions not only function as a criterion for preserving the physical significance, geometric relationships and scale between the old and new structures, but they also play role in the matter of non physical aspects, establishing balance in functional performance as well as aesthetic and human qualities. Attention to the various dimensions of proportion ensures equilibrium between elements of the new structure and the valuable building. Accordingly, maintaining proportional relationships is one of the most critical factors influencing the quality of infill design in valuable buildings; overlooking this criterion has led to a gap between the new construction and the old structure.

The main question of this article is: Which dimension of proportion (physical, functional, aesthetic, or human) plays the most influential role in infill design? Therefore, the relevant definitions within the theoretical literature are examined.

Research Background

Camillo Sitte considered the value of every building to be dependent on its surrounding environment. His focus was on the spatial relationships between a building and its setting, rather than on the functional relations of buildings with adjacent open spaces. Giovannoni believed that modern architecture lacked a distinct style and argued that we do not have the right to construct a contemporary modern building next to a historic one; doing so, would constitute an insult to the historic building's original style. His proposed solution was that, when constructing a new structure or completing a damaged portion adjacent to an ancient and valuable building, the original architectural style must be followed and abstracted. The new building should not generate a new style nor introduce ornamentation (Ghadiri, 2024, 13–14). Contextualism in Western architecture first gained attention in the 1980s. In Brent C. Brolin's book "Framing the field: A Primer on the Contextualization of Architecture" (1980), the concept of contextualism is discussed along with numerous examples demonstrating appropriate approaches to dealing with architectural context. Likewise, ICCROM, in Section Nine of the book "Managing Cultural World Heritage", specifically within the chapter Urban Planning and Cities with Archaeological Heritage Worldwide, presents the results of collaborations among conservation specialists and World Heritage managers from various countries. The term infill buildings, referring to the insertion of new structures within historical contexts, was introduced for the first time in this publication, where its characteristics were also examined (Anjom Shoae et al, 2019, 68–69). In the article "Foundations of Infill Buildings in Historic Contexts Based on International Charters and Declarations", MohammadMasoud and Hamidreza Beigzadeh argue that precise knowledge of the context, acknowledgment of both physical and non physical criteria, legitimization of innovative and

creative modes, coherence between the new structure and the historic building, preservation of the urban image, inspiration from indigenous historical patterns without literal imitation, and improving quality of life through appropriate architectural design (Masoud & Beigzadeh Shahraki, 2014, 106). But how is the coherence and legitimacy of these criteria actually formed? In the article " Design Guidelines for New Constructions in Historic Context", Shah Teimori and Mazaherian conclude that when the presence of new structures within historic contexts becomes necessary, the design of the new buildings must be compatible with the existing historical setting (Shah Teimori & Mazaherian, 2012, 38). In their study, proportions are mentioned as a sub criterion of scale, yet the details of this concept remain unexplored. Anjom Shoae et al. (2019), in their article "Principles and Strategies for Designing Infill Structures as driving Development of Historic Fabrics", emphasize that new infill structures must be compatible with the historic fabric and the adjacent buildings, however, the new design must also represent contemporary architecture and should not simply replicate the past (Anjom Shoae et al., 2019, 77). Their work highlights the importance of scale thus, the necessity of adhering to physical, human, and functional proportions as design strategies for new constructions. Another article, "Analysis of the Physical Criteria of Infill Buildings to be Used in Design and Evaluation", written by Niaei, Daneshjoo, and Bemanian, examines scale and proportions (from the physical dimension) as supportive approaches to infill design. Although physical proportions are addressed, the study lacks a perspective that treats proportions as the central mechanism for visual coherence (Niaei, Daneshjoo & Bemanian, 2021, 55). A review of the research background shows that while Sitte alluded to components of infill integration, he did not systematically focus on any single criterion. Likewise, recent national studies have referenced form, shape, and geometry, but a comprehensive framework for evaluating proportions in infill design remains absent. Overlooking this criterion which is among the first aspects perceived by users can lead to a gap in the relationship between the old and the new structures.

Research Method

This study employs analytical–descriptive methods to explain the extent and manner in which various dimensions of proportion influence infill design. To classify the indicators and criteria related to proportions in infill architecture, validated academic and library sources were reviewed for the theoretical discussions. In this research, proportions were categorized into four main criteria: "physical", "functional", "human", and "aesthetic", each of which was further subdivided into several sub criteria. Evaluation of the criteria and sub criteria was carried out through a questionnaire, completed by 15 experts including professors, designers, and specialists in architecture and restoration who possessed professional experience in infill design. The reliability of the data was assessed using Spss 26. Through the Analytic Hierarchy Process (Ahp), the ranking and identification of the most influential proportion criterion in infill design were determined. Subsequently, using the (Topsis) method, the efficiency level of the criteria and sub criteria for the infill design of the Rasht Flour Milling Factory (the case study) was evaluated, and the results were analyzed by the authors.

Theoretical Foundations

• Infill building

The significance of infill design lies in developing vacant or fragmented plots, as well as in constructing new buildings within urban and peri urban areas. Infill developments encompass several forms, including reconstruction or expansion of existing structures, construction on vacant land, and adaptive reuse of underutilized sites such as parking lots and former industrial zones (Rahmat et al., 2022, 2). In other words, infill buildings refer to new structures introduced into empty spaces created through natural or human induced deterioration within the existing fabric. These structures fill the gaps between the existing urban grains and integrate into the surrounding built environment (Anjom Shoae et al., 2019, 70).

• Infill architecture's study area

The field of architecture should adopt a multidimensional perspective on the subject of infill. When designing within a historic context, architects are obligated to consider the preservation of the existing fabric and buildings, contribute to the continuity and entirety of the city, revitalize and restore urban life to the area, while simultaneously responding to evolving cultural, social, and aesthetic values, societal expectations, introducing contemporary architecture, and adding a relevant historical layer to the existing historical layer. (Gharebaglou et al., 2019, 62). Consequently, within the study area of architecture, attention must also be paid to the orientations of urban planning and

conservation fields to meet the values pertinent to the existing city and building.

The effectiveness of an infill building is determined by the quality of its relationship with the existing elements. Proportions play a crucial role in the visual and physical aspects, influencing human perception of the building, spatial functionality, and aesthetic quality. Therefore, studying proportions can provide guidance for infill design, enabling the creation of a new building that not only preserves the value of the existing structure but also generates its own distinct values.

• Proportions in architecture

The aim of theories on proportions is to evoke a sense of order and harmony among elements within a visual structure. A proportion system establishes coherent visual relationships between the components of a building, as well as the building as a whole. Ching, in his book, notes that proportion systems extend beyond functional, technical, formal, and spatial aspects of architecture to encompass aesthetic considerations (Ching, 2015, 306-313). Similarly, quoting Vitruvius, proportion is the correspondence of the sizes of the various parts of an architectural work to one another. Steve Bass, in his book "A Theory of Proportions in Architecture and Design", posits that elements and archetypes are described by number and geometry, i.e., by proportion. Thus, in a classical composition, proportion gives each element a comprehensible relationship to every other part and to the whole. If beauty is the goal, then proportion is the tool employed to create a "sense of unity" a feeling that paves the way for the experience of beauty. It is important to remember that proportion is not the subject of art, but its method; it is a structure in the background or an underlying structure to be imitated (Bass, 2023, 37).

• Physical proportions

Physical proportions involve assessing the scale of an infill building in relation to its surroundings in terms of height, volume, density, and context. These types of proportions dictate how architectural elements should be arranged to create a comprehensible structure. This aspect is doubly important in infill architecture because the new building will be situated within a context where proportions have already been defined by existing structures. Therefore, any new intervention can impact the quality of both buildings. One of humanity's intuitive faculties is the perception of subtle mathematical proportions in the physical world. Just as musical instruments can be finely tuned with proportionate adjustments to create harmony, we possess a similar capacity for understanding visual and spatial proportional relationships (Holl et al., 2016, 128). Our perception of the physical dimensions of architecture, scale, and precise proportions is not exact and is influenced by perspective, distances, and even varying cultural and personal biases (Ching, 2015, 312).

• Functional proportions

Architecture derives its value from its capacity to fulfill specific functions and tasks. If function is removed, value is lost (Heidari, 2018, 95). As emphasized in the principles of modern architecture by Louis Sullivan's motto, "form follows function" (1896), the physical proportions of a structure must be such that they facilitate user activities. To this end, functional proportions focus on spatial efficiency. In essence, functional proportions regulate the physical relationships based on user requirements.

• Human proportions

Human proportions refer to the relationship between the components of a building and the parts of the human body. Adherence to these proportions results in greater psychological and perceptual satisfaction for users, making the space more pleasant for them. Throughout history, humanity has created tools that, in order to serve them, needed to be sized in relation to human dimensions. Human body parts have historically been considered the primary units of measurement (Neufert, 2017, 26). From Vitruvius's perspective, the human body is the measure for assessing proportions in architecture, and architecture is considered complete when its ratios harmonize with human dimensions. In Iranian architecture, the concept of human scale which Mohammad¬Karim Pirnia discussed in his book, refers to respecting the proportions between the shapes of the building and the shapes of the human body, and overall attention to human needs. According to Holl et al. (2016), historically, the tradition of specific construction in each culture, exemplified by the Japanese tatami mat, establishes relationships between room sizes based on the tatami and human scale. Consequently, the building naturally takes shape based on the human scale and a harmonious system of relationships (Holl et al., 2016, 128).

• Aesthetic proportions

In aesthetic proportions, beauty arises from the relationship between the parts and the entirety of the volume. The understanding of the nature of rational ratios formed by integers, and transcendent ratios such as the golden ratio which are not composed of

integers, serves as an approach to achieving beauty (Bass, 2023, 2). If we diminish the qualitative aspects of architecture and focus solely on the quantitative aspects of engineering sciences, we severely degrade it. Qualities emerge from the combination of shapes, colors, sizes, and materials (Heidari, 2018, 96).

Ultimately, all criteria of proportion (physical, functional, human, and aesthetic) evolve in harmony with and alongside each other. Proportions refer to the harmonious relationship between the sub-criteria within one section, and the relationship between one section and another. These relationships do not only pertain to dimensions but also encompass quantities. While there is a wide choice, some of these selections are dictated by the nature of the materials, the way building elements react to forces, and the method of object construction (Ching, 2015, 306).

Research Findings

The research findings were gathered through a questionnaire distributed to 15 experts in architecture, restoration, and infill studies. The questionnaire determined the importance and impact of the four criteria of proportions, as well as their sub-criteria, in the infill design of the Rasht Flour Factory (the case study). (Fig. 1) illustrates the criteria and sub-criteria.

Using Spss 26 software, Cronbach's alpha test was initially applied to the entire questionnaire and subsequently, separately, to each of the four criteria of proportions (physical, functional, human, aesthetic). Due to the limitation of Cronbach's alpha application for scales with fewer than three components, the correlation coefficient was used for shorter sections within the sub-criteria. The overall Cronbach's alpha for the questionnaire was (0.76), indicating acceptable reliability.

In the next stage, the average of each proportion criterion was calculated using Excel. To rank and determine the most effective proportion criterion, (Ahp) Process was employed. This involved an initial pairwise comparison between the main proportion criteria, followed by comparisons among the sub-criteria within each category, ultimately yielding relative weights. The overall (CR) for the questionnaire was obtained at (1.1%), indicating adequate consistency among the criteria. To measure the actual impact of each criterion, weighted scores and the percentage contribution of each criterion and sub-criterion were calculated. To examine the stability of the results, a sensitivity analysis was performed by altering the weights of the main criteria by 5%. As a result of this stage, adding or subtracting a negligible amount to the weights maintained the established ranking and priorities from the previous analysis within the components. For ranking and selecting the most ideal option, the TOPSIS multi-criteria decision-making method was utilized, and the normalized decision matrix yielded the final scores for each component (Table 1).

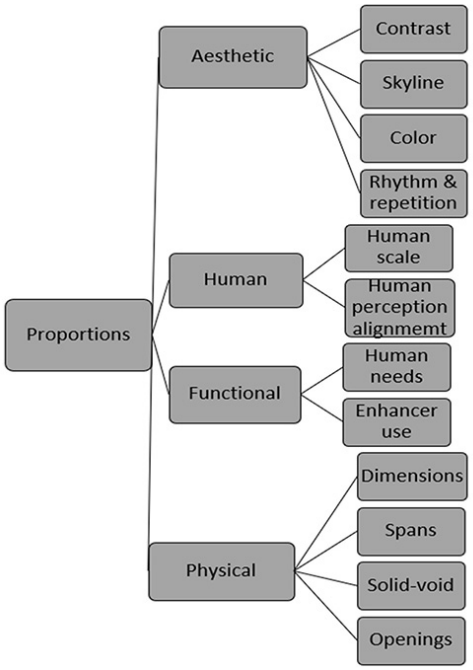

Fig. 1. Criteria and sub-criteria of proportions. Source: Authors.

As a result of the analysis among the four main criteria of the research, Functional proportions and after that Physical Proportions, Aesthetic proportions, and Human Proportions are significant in relation to one another (Fig. 2).

Based on the conducted analyses and consideration of the collected data, the final score for Functional proportions, with a weight of (0.131), secured the first rank. This finding indicates that attention to site requirements and usages that enhance spatial functionality has a greater impact on infill design compared to other proportions. Infill design gains meaning when the new function can effectively operate within the process of building regeneration and strengthening the context's functionality (Fig. 3).

In second place is Physical proportions with a weight of (0.075). According to the experts, paying attention to dimensions, physical characteristics of the building, openings, and spans can deliver high-quality coexistence between the new and the older building (Fig. 4).

Occupying the third position is Aesthetic proportions

Table 1. Final scores for each criterion. Note:(The weights of the sub-criteria have been calculated and normalized relative to other sub-criteria within their respective groups and are only comparable to sub-criteria within the same group. They are not directly comparable to the final weight of the main dimension). Source: Authors.

Main Dimension	Final Score	Sub-criteria	Final Score
Physical proportions	0.075	Dimensions (Compared to the factory building)	0.044
		Dimensions (Compared to the neighborhood)	0.046
		Spans	0.036
		Solid-void	0.044
		Openings	0.022
Functional proportions	0.131	Site needs	0.070
		Enhancer use	0.065
Human proportions	0.018	Human scale	0.295
		Human perception alignment	0.20
Aesthetic proportions	0.036	Contrast	0.056
		Skyline	0.117
		Color	0.045
		Rhythm & repetition	0.030

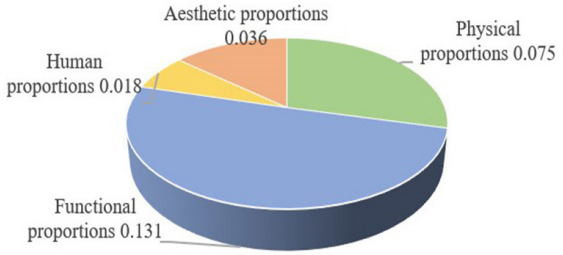

Fig. 2. Final scores for each criterion. Source: Authors.

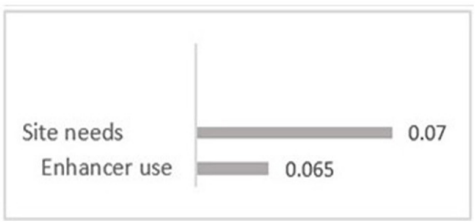

Fig. 3. Final scores of sub-criteria within functional proportions. Source: Authors.

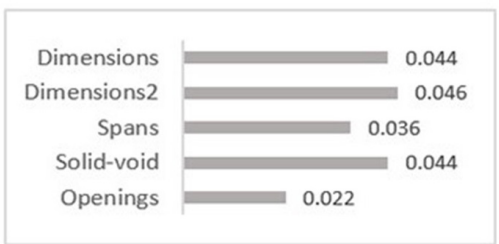

Fig. 4. Final scores of sub-criteria within physical proportions. Source: Authors.

with a weight of (0.036). Emphasizing these proportions can be regarded as a tool for establishing a meaningful connection between the infill building and the existing structure. Factors such as rhythm, repetition, skyline, and controlled contrast are also important and receive attention alongside this criterion (Fig. 5).

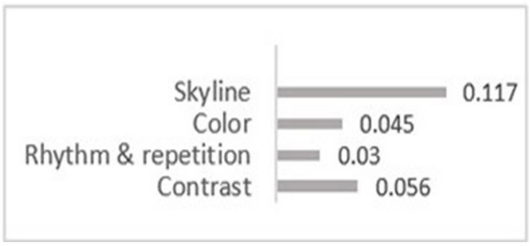

Fig. 5. Final scores of sub-criteria for aesthetic proportions. Source: Authors.

Finally, attention to Human proportions with a weight of (0.018) is placed. From the specialists' perspective, the quality of infill design is not solely determined by harmony in form or concept. Ultimately, the purpose of any architectural structure is its consumer: human beings. Human proportions are the criteria that determine the quality of the user's presence (Fig. 6).

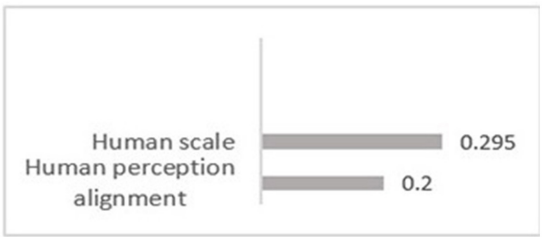

Fig. 6. Final scores of sub-criteria within human proportions. Source: Authors.

The research evidence demonstrates that in the infill design process, attention to Functional proportions and subsequently Physical proportions plays the main role in enhancing the quality of the infill building. Aesthetic and Human proportions, although ranked lower in priority, still exert a significant influence on infill design and contribute to improving the harmony of proportions between the infill building and the valued existing structure (Table 2).

Conclusion

The research findings indicate that in the design process, proportions are utilized as an index for determining the quality of infill structures. Following the analysis of the four proportion criteria on the Rasht Flour Milling Factory case study, experts placed the greatest emphasis on functional proportions. Attention to user needs, compatibility of the new structure's

Table 2. Design Criterions. Source: Authors.

Row	Main Design Criterion	Sub-criteria	Impact in Design
1	Functional proportions	Site needs- Enhancer use	Use responsive to human needs
2	Physical proportions	Dimensions- spans- Solid & void Openings-	Maintaining visual proportions in building design to create harmony between new and old structures and with the neighborhood context
3	Aesthetic proportions	Skyline-Contrast-Color- Rhythm & repetition-	Attention to the skyline in harmony with surrounding buildings, creating controlled contrast in the new building's components, and considering appropriate harmony in color and rhythm
4	Human proportions	Human scale-Human perception alignment	Harmonizing proportions with human scale to enhance the sense of identity in buildings

function, and the enhancement and completion of the context's existing use are the characteristics of this criterion. Addressing the identity of the design context and creating new structures that can accommodate the existing function, compensate for its deficiencies, and enable broader and more efficient use of the context by the new structure are among the responsibilities of the functional proportions section, and can significantly contribute to the success of the infill structure.

The second most influential criterion identified was physical proportions. An examination of the sub-criteria for this aspect reveals that the new structure should not obstruct the context in terms of height and scale; it should progress in harmony with the context, and ultimately, interaction should be established between the new structure and the context. In infill design, attention to physical proportions means creating visual continuity while respecting the proportions of the context and neighboring buildings.

The two criteria of aesthetic proportions and human proportions were ranked as the third and fourth most considered criteria by experts, are essential and significant for advancing infill design. Expert attention and emphasis on the sub-criteria of aesthetic proportions, such as the high importance of the skyline, creating conscious contrast, as well as considering human scale in infill design after focusing on the building's function and its physical dimensions, can be an effective tool for infill interventions.

Clearly, attention to the aesthetics of a building, as well as being human-proportionate, have always been among the fundamental principles and prerequisites of designing any building, and are of high importance, just like attention to function and physical form. However, functional deficiencies in some existing constructions, which have arisen after the revitalization of valuable buildings and the imposition of new uses onto old structures, have caused concern among specialists, leading to more meticulous scrutiny of this issue. Therefore, attention to functional proportions has become relatively more prioritized than other proportions. The findings are focused on the specific building under study, and their generalizability applies to similar project conditions. The prioritization of proportion criteria may change depending on the specific context of each city and evolving needs over time.

The results of this research serve as a step towards enhancing the design level of new infill structures. Designers can test the compatibility of their designs with the context using these proportions before implementation and consider them in their decision-making processes.

The relatively limited sample size of the questionnaire (15 participants) is capable of reflecting initial results, but the scope of application for these findings is mainly limited to projects similar to the case study. It is suggested for future research to investigate proportions at larger scales and in the domains of restoration and vertical urban expansion, which would complete the analytical models for assessing the coexistence of new structures and their contexts.

Conflict of Interest

The authors declare that there was no conflict for them in conducting this research.

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HOW TO CITE THIS ARTICLE
Khadem, A., & Faroughi, S. M. (2026). Proportions in Infill Design, The Connecting Criterion Between New and Old Structures. *Journal of Revitalization School, 3*(10), 26-33.
DOI: https://doi.org/10.22034/4.10.3
URL: https://jors-sj.com/article-1-103-en.html