Architecture-&-Building Systems: Notion and Evolution

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Abstract. The article deals with the role of Architecture-&-Building systems in Civil construction in the process of their historical development. The concept, definition, structural model and evolution of the Architecture-&-Building Systems and it subsystems are identified and considered. The purpose of this research is an attempt to define the notion of Architecture-&-Building Systems and analyse the history of their development as the main material and technical means for the implementation (creation) of the architectural environment.

1. Introduction

Architecture-&-Building Systems (ABSs) are the decisive material and technical means for implementing the architectural environment and play a leading role in the solution of housing problem and sustainable development. They have a significant role in accelerating scientific and technological progress in the field of architecture and urban development. This term is used to refer to a system of coordinated architectural, constructive, and technological decisions, which proceed from a universal methodology. The ABSs are directed at forming a friendly environment and simultaneously are the material and technical means of realizing such environment of the system of material entities [1].

At the same time, the need to create a fully-fledged living environment and solve the problems of the complexity and aesthetic qualities of residential development depends largely on the use of advanced architectural and urban development solutions and the implementation of efficient building structures, materials, products, and technologies, and the improvement and transformation of the material and technical base of construction [2,3,4]. It should be noted the availability of modern methods for the integrated assessment of such solutions in the context of sustainable design [3,4]. At the same time the key issue is determining the development strategy and prospects for improving the architectural and construction systems of civilian buildings.

Such systems are known in housing practice. It's basically like prefabricated large-panel systems, prefabricated framework systems, modular cell systems, block systems, monolithic systems, and their combinations, but they do not always meet modern social and economic requirements and constantly improving. At present the building market is changing and growing, featuring new diverse construction decisions [1-8]. For a holistic view and a comprehensive solution of this problem, it is necessary to consider and define the concept, definition and evolution of the ABS, what is the purpose of this article.

2. Notion

The term “Architecture-&-Building system” (ABS) is not new in design and construction practice. It is widely used in various studies and publications, normative and methodological documents, mostly in Eastern Europe. However, there is no a clear definition of this term. Along with this, terms such as
industrial systems, building design and construction systems, prefabricated systems, framework systems and others are used [1,3,5,6,7,9]. At the same time in the most part of various publications buildings and structures and their constructive components and elements as systems are considered. Before giving the terminological definition of ABS, one should consider the existing terminology of related concepts.

The most common and stable term is "constructive system" (CS). However, this term is interpreted differently in various studies [8,9,10]. As the functional and architectural aspects are usually crucial for the CS, the most reliable interpretation of it as a subsystem of the architectural system is given in the studies by Professor B. G. Barkin:

"The constructive subsystem is realized by material and technical means and provides stability, strength, durability and fire safety" [10, p.90]. In other words, a constructive system should be considered as part of more complex systems - architecture & constructive (architectural & structural) and architecture & building (architectural & construction), in which no constructive element or part can be constructed and evaluated in isolation. Ignoring such design leads to serious mistakes, failures, violations of the relationship between structure and form, worsening conditions of buildings and so on. Examples of this may be the first prefabricated large-panel and frame-panel buildings in Eastern Europe, designed only on terms of statics, technology and economy of materials. Correction of such errors in the conditions of factory homebuilding requires a restructuring of production and leads to economic and moral losses.

In this regard, it is logical and justified, in our opinion, the emergence and spread of the term architecture and constructive system (ACS), which subsequently became applied in farther researches and design [8]. However, despite this, the definition of this term is absent. Along with this became the extension of a term as a building system (BS), which is a combination of a certain construction method with a certain constructive system in the application of specific technology. In turn, the construction method is a way of erection of buildings, for example, a large-panel or monolithic method (Figure 1).

In addition, other definitions and terms that belong to the subject of research and reflect its essence (mainly a technical point of view) are known - structural and technological systems, design and production systems, systems of industrial residential houses, etc. [1-7].

The given terminology does not exhaust all the definitions adopted by different experts, which often complement each other, but generally have a local character, since in most of them lack such an important and comprehensive concept as the architecture, which underlies both constructive and building systems. This largely reflects not only the functional aspect from the point of view of terminology, but also its essential aspect.

Since the formation of each building is impossible without a complex of architectural requirements and urban conditions, it is most expedient to operate such terms as architecture & constructive systems and architectural & building systems. At the same time, the latter most accurately and fully reflects the phenomenon of the integration of architecture and industrial homebuilding and embodies in its name the whole complex of not only urban, architectural, constructional, but also construction and technology issues (Figure 1).

The author understands the architecture & building system as a set of interrelated architectural, productive and technological solutions, which are based on uniform methodological principles of housing environment formation and provide realization of a complex of socio-demographic, urban planning, functional and lay out, technical, technological, environmental, economic, aesthetic and other requirements [1, p. 13].

It should be noted that in fact the concept of ABS is two aspects of one phenomenon. The first is material and technical aspect, which is included in the system of material formations and technical means of realization of the living environment - from building to the apartment, and the second aspect is organizational and informational, which is examined in the system of public relations and management of urban planning as a certain program of appropriate targeted actions. In accordance with the terminology we adopt, architecture & building systems of civil engineering, intended to form
a residential environment, should be presented in three main aspects: functional-spatial, constructive, and construction-technological. It can clearly define the range of phenomena associated with the organization and design of the material and spatial environment, which has an important methodological significance.

![Diagram](image.png)

**Figure 1.** Main characteristics of systems of civil construction

The ABS model (Figure 2) should be considered as a complex system, which includes three subsystems: functional-spatial (architectural-lay out), constructive (tectonic), technological (production-building).

Each of these subsystems has a hierarchical range of its own interrelated structural elements, the further classification of which has an open nature that takes into account the multidimensional information and the degree of its interaction with other elements and their groups in solving specific architectural and construction tasks. Construction of the model structure of architecture & building systems and its operation will provide an opportunity to determine the nature of the system's behaviour, predict its future state, trends and development prospects [1].
3. Evolution
The usage of different construction products and prefabricated elements of ABS for the construction of buildings is known for a long time. Even in the period of pre-class and early-class society the human has mastered the usage of basic natural building materials, learned their processing and artificial manufacturing (wood, brick raw, burnt bricks, stone, mortar). The main construction elements emerge: foundations, solid walls, rack-beam fence systems, beam and vaulted ceilings. With the lapse of time, a coherent scheme of composition building was formed: tectonic construction of the wall, decoration rack-beam design in the form of order system, certain architectural and design principles of proportional construction of buildings and their individual parts.

In the early birth of architecture two ways of fencing of space were used: a blank wall and rhythmically arranged vertical pillars. As the prototype of the second option, the central part of cromlech in Stonehenge (England, second half of the 2nd millennium BC) can be considered. In this round building with a diameter of 30 m, the idea of rack-beam structural system and architectural mass distribution for the active and passive elements was expressed brightly. Framed structures emerged in the same time period. Framed by the constructive solution were constructed of woven reeds, stuck on wooden risers, the oldest sanctuary of early kingdoms of Egypt (third millennium BC). Further development of pillar-beam structure has covered various countries of the ancient world. Gradually an order was formed - still system of pillar-beam structures subordinated to laws of certain figurative doctrine according to which the dimensions are determined depending on the module, acquiring specific proportions. The basis of the order was artistically designed vertical pillar with the base and capital-column supporting a horizontal element - beamed ceiling (entablature).

Forming of order system in the ancient world began in ancient Egypt. First there were the pillars of square section, later - support in the form of cylinder with cannelures of irregular curvature. Later, there were capitals as abaca and base - rectangular or round plate. Subsequently, the column began to follow the form of the plant world, several types of capitals emerged. Extreme solidity of columns (height equal from 3.75 to 7 diameters) emphasized the same narrow intercolumniations. A massive architrave topped the columns. All the structures had a huge margin of strength [11]. Fust of column was mounted of barrels of crystalline sandstone, carefully adjusted to each other (Figure 3).
For the era of the formation of ancient Greek architecture building of wood and blocks of brick raw was typical. At the end of this period the fine assembly element appeared - scorched clay rooftops. During early Archaic period (VIII - early VI century BC) wood-adobe technique continues to dominate, combined (in temple construction) with extensive use of terracotta cladding. Since the end of VII century BC limestone blocks become widely used, and later - marble blocks. At this time certain types of churches and other public buildings were formed, and along with them - the main options for Greek architectural orders. The most famous orders, developed in ancient Greece are Doric, Ionic and Corinthian. The heyday of the Greek ancient architecture accounts for the classic period (480 - 400 BC), when prominent place in all areas of public life ought to Athens. At this time a masterpiece of world architecture - the buildings of the Acropolis of Athens had been created, where fairly limited range of standard building elements of marble had been used. The step of columns in buildings with the application of this material, that is much stronger than the Egyptian sandstone, significantly increased (Figure 4).

Order system - is one of the most important contributions of ancient Greece to the further development of world architecture. It has been successfully applied even in 2000 years by other nations and in completely different historical conditions for solving various architectural tasks. The concept of original order system can be used for various pillar-beam systems using the specifics of local building materials, that took place in the architecture of ancient China and India, Iran era of Achaemenid Empire, other countries [11].

Borrowing from ancient Greece the order system, architects of ancient Rome complemented her with Tuscan and Composite orders. Based also on the achievements of architecture and construction of the Etruscans, the Romans reached new heights in the world of architecture. Since the end of the second century BC burnt bricks of various shapes was used: in addition to the usual bricks, round bricks for building columns, bricks with voids - for arranging the heating system.

Besides the pillar-beam system of buildings and structures apparent arch and apparent vault appear due to the invention and application of new mortar. By the end of the third century BC invention of Roman concrete was done, which opened huge opportunities in construction. The combination of concrete technique and arch-vault constructions had a huge impact on the Roman architecture. Only on the basis of those construction technologies it was possible to create such monumental structures as Porticus Aemilia, Roman aqueducts, the Colosseum and the Pantheon. (Figure 5). It should be noted that the typification of the main structural elements was widely used in design, the multiplicity of their size and foot modularity, which allowed to separate construction work into some simple operations [11].

Byzantine architecture (VI - XV centuries) was based on the Greek-Hellenistic traditions, as well as directly on Roman architecture and was under the influence of cultures of the Middle East, in close connection with Christianity.

Vaults and domes of large diameter above the squinches, borrowed from the Middle East, combined with traditional Roman detail. One of the greatest achievements of Byzantine architecture is a new constructive solution of the transition from the square plan of room or building to the hemispherical dome using the pendentive/sail (Figure 6) In localities with deposits of natural stone, hewn blocks of stone were used as the building blocks, and the burnt brick, particularly indispensable in curvilinear designs (arcades, baths, etc.) - in other regions.
Romanesque architecture (IX - XIII) was started in the north of modern Italy, France and West Germany. Romanesque cylindrical cruciform arches, semicircular arches, rubble concrete core of walls and towers with the cladding slabs of hewn natural stone are inherited from ancient Roman structures. Kind of innovation was the emergence of ribs in the massive stone vault. The Romanesque stone cylindrical column had no established proportions. Capital, similar to Byzantine, had small cut downwards cube shape, or the shape of a cup, with carving and facets. Hewn blocks of limestone, sandstone, granite were the main building material. The experience of building vaults of hewn stone, accumulated during this period was of great importance for the subsequent history of architecture (Figure 7.).

The Gothic architecture - a new structural system that originated in north-western France (mid-12th century), spread in Western Europe before 15th century, and in Eastern Europe, before 16th century. A characteristic feature of Gothic architecture is the preference of vertical elements and improving techniques of vaults construction. Romanesque rib arrays of the vault was transformed into the frame, which required only filling with light stone slabs. Further study of the interaction of forces arising in the construction of vaults, led to the first use of high arch, and later - the pointed (lancet) arch. It changed the angle between the direction of vault thrust force and vertical support, which increased the height of the vertical supporting columns with simultaneous reduction of the area of their section. That allowed to cover much longer runs.

After improving designs of flying buttresses and buttresses a slim frame building system has developed, which in turn contributed to the creation of grandiose temples that besides religious functions served as urban public facilities. At the same time structural elements in Gothic architecture clearly differ from fillings. Hewn blocks of natural stone were the building material, and in Northern Europe, where stone was almost absent, it was fired bricks, decorated with stripes and modest ornamentation of glazed brick (Figure 8).
The architecture of the Renaissance (1420 - 1540) originated in Italy. It was based on creative
development and use the architectural heritage of antiquity, especially classical order system in the
new historical conditions.
Unlike previous eras, where the main focus was on defense and iconic building, during the
Renaissance civil and residential construction gets more importance. New types of public buildings
appear, the type of ceremonial residence of the lord is formed. The clear planned palace complex
emerges, an essential component of which is rectangular or square front Cour d'honneur, surrounded
by open arcades and galleries. The structures of Renaissance domes on pendentives followed the
Roman and Byzantine designs. One of the innovations in design of vaults are so-called "mirror" vault,
which was based on the Roman monastery vault [11].

The architecture of Baroque era (1580 - 1780) originated in Italy, then it spread over Europe and
Spanish colonies in Latin America. Conventionally divided into three stages: early, developed (high)
and late, sometimes allocated a separate style - the Rococo. Baroque architecture is characterized by
sharp contrasts of volumes, dynamic compositions, the plasticity of facades, black and white effects,
created by a complex configuration of the facades, the use of curved architectural elements and
doubling of architectural details (columns, pilasters), "dissociation" of gables and cornices (Figure 9).
Vertical support - the column - in baroque architecture often transforms from the active structural
element to the purely decorative. Engaged columns, forming expressive compositions on facades and
in the interior take load only from pilaster side of massive entablature and rich decor masks the
structure of architectural form [1,11].

The frame system achieved high perfection in wooden houses of feudalism era in Eastern and
South-East Asia - China, Korea and Japan.

Formed at the beginning of a new era types of buildings have become traditional for centuries and
have not experienced significant changes. The main of them - rectangular building with a unified
interior space. Wooden framing of buildings that emerged in ancient times got further development.
The frame with filling the gaps between pillars with wooden panels, and for large runs consisted of
several articulations. An integral part of the framework of the system was special hard roof design,
which was connected with the brackets to the frame supports. These brackets with various decoration
were characteristic structural elements of Chinese buildings (Figure 10).
With the spread of Buddhism in China the new by appointment and architectural image highly characteristic for the region type of church - tower-pagoda have emerged, which basis is the brilliantly solved complex framing. Ancient wooden pagodas and Buddhist monasteries of Japan reiterated the overall composition and form of Chinese buildings.

Utmost simplicity of frame wooden structure of Japanese apartment building, standard parts - pillars, floors, sliding external and internal walls-panels are due to the use of a certain module in these buildings. The principles of modularity and typification, the possibility of transforming the premises attract the attention of modern architects around the world to the architecture of traditional Japanese homes.

Since the second half of the nineteenth century and the beginning of mass building in Europe and North America started to appear and actively spread prefabricated structures of various building materials. Analysis of the evolution of architectural and building systems revealed the two main ways of their formation and development:

- ABS, designed for the construction of one or more buildings on the basis of specially made architectural building elements (Figure 11);
- ABS, intended for mass construction of buildings on the basis of serial production of unified architectural and building products and components (Figure 12).

The development of residential and civil building shows that from ancient times to the early twentieth century, the first trend was dominant in the history of the evolution of ABS.

The second trend, which has several historical stages of ABS evolution, marked with the industrial revolution with the introduction of replacement of manual labour with a large system of industrial production in Europe in the second half of 18th century. During this initial period of industrialization iron production took on a new meaning at relatively restricted usage of in buildings of antiquity and the Renaissance. In 1767 in England the first cast-iron rails were made, and 10 years later the iron bridge was built over the Severn river. Cast-iron risers were the first part of the building structure, made under new industrial methods. Already in 1780, even before the steam age, those risers replaced the wooden roof supports of first English cotton mills. Later, the use of iron structures allowed to place the mechanic equipment on all floors of buildings [12].

Figure 9. Baroque church

Figure 10. Architecture of Ancient China
Figure 11. ABS, based on specially created buildings elements: 1 – Antiquity; 2 - Middle ages; 3 – Renaissance

The mill near Manchester, built in 1783, may serve to illustrate the initial phase of development of industrial construction. This factory was one of the first with iron risers, established in the interior. The next step to progress was the use of iron frame loft constructions of cotton mills in England since 1835. Cotton mill of Philip and Lee, built in Salford (Manchester County) in 1801, is the second example of early usage of cast iron structures [1,12]. This mills differs from the others built in this period, with venturesome architectural solutions. It is the first experiment in creating a single internal frame of the building, which consists of iron uprights and crossbars. Construction of this building is a primary event in the history of modern structures.

Cast iron risers were used in combination with stone, brick and wood. For nearly a century cast-iron column played a leading role in the construction of various buildings in the world. It was used in a variety of architectural purposes throughout the nineteenth century. In the Crystal Palace, in the Royal Pavilion in Brighton, covered markets, libraries and even in the first skyscrapers built in Chicago, cast iron riser served as the main supporting column. A wide spread in Britain - and much wider in America - in the 40s of the nineteenth century cast iron columns had in the facade solutions of buildings, as well as in the construction of load-bearing structures. The reason that in the nineteenth century cast iron was the dominant material is its fire resistance, low cost, ease of manufacture and high bearing capacity. These benefits were enough to ensure the domination of cast iron as a material for risers and columns until the 70s of the twentieth century, when steel frames were used in Chicago for the first time. Since the second half of the nineteenth century rolled I-beams become used in construction due to invention of equipment for the production of rolled steel and beams (Figure 13).

The first skyscraper, designed and built according to new principles of design of that time was ten-storey building of the insurance company in Chicago. T
The company needed a new type of office building, which would be fire-resistant and would ensure a maximum level of lighting in working premises. As a result, not much more than eight decades have passed between the construction of the seven-storey textile factory with iron columns and beams and construction of the first skyscraper with a metal frame [12].

![Figure 12. The stages of evolution of ABS for mass buildings on the basis of serial production.](image)

In the 1880s together with the rapid spread of a new steel structures, the new building material appeared - concrete, whose influence on architecture manifested exceptionally fast. In 1884, construction of first church of reinforced concrete frame and thin fencing walls began in Paris by the design of architect Anatole de Bordeaux. In the construction of residential houses August Perret in Paris used reinforced concrete for the first time. Since the beginning of the twentieth century, reinforced concrete was used almost everywhere. The prominent “buildings-representatives”:
- sanatorium in Davos (Switzerland), 1907;
- “Montgomery Ward & Co.” storehouse, Chicago (USA), 1908;
- the garage, designed by August Perret in Paris, 1910;
- residential building designed by Le Corbusier in the Swiss Jura Mountains, 1916.

According to the accurate expression of Siegfried Gideon [12], reinforced concrete between 1910 and 1920 became a symbol of architecture.

It is no accident that first architects mastering this plastic building material and got their inspiration from it, known as architects-constructors and architects-engineers. The most skillful implementation of concrete frame in means of architectural expressiveness was done by Charles Le Corbusier. With a broad introduction of reinforced concrete methods of building developed and refined on its base using prefabricated and monolithic house-building. Along with this improvement and widespread use of steel structures in architecture went further. The masters of architecture Frank Lloyd Wright, Walter Gropius, Mies van der Rohe, Alvar Aalto and others were bright examples in the usage of new materials and structures in building of cities in the first half of the twentieth century (Figure 14).
The second half of the twentieth century was marked by the intensification of urbanization and the rapid post-war construction, including industrial prefabricated house building with further improvement of reinforced concrete and metal structures. The construction of famous opera house in Sydney by the design of architect Jørn Utzon, which has become a symbol of the city, was a landmark event in the 1960s (Figure 15).

However, at this time various plastic and glued wooden structures, three-block house building, various combined architectural and building systems are developed and implemented.

Full modular construction of pre-fabricated concrete structures has got the biggest development in 1950-60s, mainly in France, Denmark, and later in all countries of Eastern Europe mainly at the mass construction of so-called "social housing". In the Netherlands, this way of construction for residents with low and middle income still takes a significant amount (Figure 16).

The analysis of experience of civil construction and its structure regarding its applicable ABS shows that the construction of buildings with full modular reinforced concrete structures does not exceed 25%. In the USA prefabricated concrete decking for overlap types TT and T have gained wide spread. With these decks not only overlaps are mounted, but sometimes also the bearing walls of buildings. One of the most popular systems are prefabricated structures made of metal or reinforced concrete structures in combination with the external barriers from local materials, light metal or of glass monoliths. Monolithic and combined prefabricated monolithic frame-panel and frame-barreled building systems, with the vertical load-bearing structures, made at the construction site, and the outer fence and horizontal load-bearing structures - at the factory received considerable spread. Along with the use of reinforced concrete load-bearing structures in many Western European countries, USA, and Japan the metal frame is widely implemented. For tall civil buildings the common type of architecture and construction systems is a modular precast-monolithic system. The method of lifting beams is used effectively herewith.
In some countries (France, Germany, Italy, Sweden, Finland, Denmark) the volume-block house building as a part of combined systems (preferred direction), as well as in its pure form, is successfully developing (Figure 17). In practice of construction of residential and public buildings of various purpose light metal structures with different principles of formation and degree of assembly: block-containers, houses with bearing walls, modular type houses, etc. have become particularly widespread.

Analyzing design and construction practices of the formation and development of ABS, we note a variety of applied systems and building technologies (Figure 18). Profound changes are taking place in relation to proceedings and usage of different variations of polymers and plastics and other advanced materials and technologies. The use of nanotechnology provides new opportunities for application design and architecture of traditional materials such as wood, metal, glass, which recently considered in the design development as the carrier material [1]. New architectural and construction systems have a number of indisputable advantages in terms of architectural and planning solutions and their capacity compared to traditional large-panel and and frame-modular systems. Expediency of their usage depends on the objective function and priority of the relevant requirements applicable to the ABS, the specific conditions for their implementation, as well as the capacity of local building materials and industrial base.

Figure 17. Modular cell system in Denmark

Figure 18. The newest ABSs. Shanghai

4. Conclusions
The solution of modern Housing and Urban Development problems is impossible without new approaches and methods of designing, development, management, and co-ordination of architectural, engineering, technological and industrial decisions. Architecture-&-Building Systems (ABSs) play here a very important role. This term is used to refer to a system of coordinated architectural, constructive, and technological decisions, which proceed from a universal methodology. In the absence of a clear definition of the ABS concept, which is common in professional language and literature, this concept is defined in the article and its interpretation is given. The proposed structure of the ABS model consists of three hierarchically subordinate subsystems and provides classification at the lower levels of elements’ generalization - up to the primary elements of architecture & building systems. It has an open character that allows it to be operated.

Analysis of the evolution of architectural and building systems revealed the two main ways of their formation and development: ABSs, designed for the construction of one or more buildings on the basis of specially made architectural building elements; ABSs, intended for mass construction of buildings on the basis of serial production of unified architectural and building products and components. The second direction has four main stages of the evolution of the ABSs, since the beginning of industrial production in the XVIII century, in line with the development of building materials, structures and technologies.

The study will provide an opportunity to consider the prospects for further development and improvement of Architecture-&-Building Systems and a wide range of architectural and engineering tasks.
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