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THE IMPACT OF MATERIAL AND CRAFTING TECHNOLOGY ON THE SHAPING AND DESIGN OF WROUGHT IRON ARCHITECTURAL ELEMENTS

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Abstract. Wrought iron was a determining material in historic times. Although it was mainly used for manufacturing tools and weapons it was also applied for architectural purposes as building structural or architectural elements. In this paper the impact of material and technology of forging on the shaping and the design of wrought iron building structural and architectural elements from the time of the first known application to the 20th century in Europe is analyzed, distinguishing five main periods which are divided by four determining technological shifts in material production and consequently forging technology. Several phenomena are delighted regarding the appearance of the artifacts and the characteristics of the material, which reveal connections between technology and architectural design. The observations are validated by visual analyses of wrought iron samples.

Keywords: wrought iron, architectural elements, material technology, construction history, iron forging technology.

Introduction

The properties of the iron alloys were determined by the production of the material for a long time. It is a well-known fact, that wrought iron is a composite of metal (iron) matrix and slag inclusions (Dillmann & Balasubramaniam, 2001). This phenomenon results in a strong, anisotropic, fibrous character of the material, that – despite the development of the material production technology – had a significant impact on the development of the artifacts up to World War I.

In the known literature, various wrought iron materials and artifacts were analyzed in many ways (Pereházy, 1982, 1984, 1986; Haas, 1983; Campbell, 1997; Gordon, 2001; Campisi & Vinci, 2003; Cecchetti & Sassu, 2003; Gordon & Knopf, 2005; Sparks, 2008; Holzer & Köck, 2009; O'Sullivan & Swailes, 2009; L'Héritier & Dillmann, 2011). This study focuses on the interaction of material, technology, and form of wrought iron building structural and architectural elements which have been investigated less frequently. Building structural elements are considered as parts of the load-bearing structures in the building, and architectural elements are the elements of the building, which play a role in the architectural shaping. Some elements, however, like the tie-rods with visible parts on the facades belong to both categories.

A detailed introduction of the various wrought iron structural and architectural element types is not the goal of this paper as it was already summarized in another study (Vidovszky & Kiss, 2008).

The technology of shaping the wrought iron artifacts was also analyzed by several authors (Kühn, 1957; Sárády, 1970; Pereházy, 1986).

The main goal of this paper is to reveal the impact of the development of iron production and iron forging technology on the evolution of the design of wrought iron building structural and architectural elements.

The forms and shapes of wrought iron cannot be deduced solely from the impacts of technical factors, albeit there are numerous well-definable technical impacts in the development of iron that do not leave doubts about the relationship between technology and shaping, as it will be demonstrated in this paper.

The appearance and shape of building structures and architectural elements evolved as a consequence of the architectural style, the technical-technological knowledge of the trade in the era, and the development of the background industry, that provides the material as a

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commodity. Regarding the relationship between design and technology, parallel phenomena can be observed in the development of different building trades. In this paper, an attempt is made to demonstrate this with the examples of smith-craft. Similarly, as it happened in the connecting field of timber doors, and windows (joinery) where the influencing factors had been the invention and spread of lumbermill and the development of woodcraft technology (Kaesz, 1995), in the case of wrought iron these factors were the invention and spread of blast furnaces and the development of the forging technology (Johannsen, 1953; Pereházy, 1986).

The milestones of most historic analyses of architectural forms and shapes are the change of styles. This kind of approach is not applicable in our case as far as the change of technology usually has no direct impact on the change of architectural styles. From this point of view, the technical requirements and opportunities have a primary role among other factors which unusual focus can reveal new aspects about the evolution of forms and shapes of wrought iron building structural and architectural elements.

Initially, in the case of the development of the construction elements the characteristic of the material, and the applied technology influenced the evolved form of the artifacts. Depending on the circumstances, the most convenient way was applied for the shaping. The investigation of the interaction between the form and the technology in the further development phases, however, is worth much deeper consideration.

A phenomenon of great relevance is, for instance, if a naturally developed form or way of manufacturing technology, which is a consequence of the characteristic of a material, is inherited in a manufacturing process applied to another material (Istvánfi, 2010). The cause of such *form transfer* could be cultural or technical. A typical cultural reason, which is independent of technological aspects, arises for instance in the case of a powerful claim for uniform architectural appearance (style) on architectural elements of different nature. An example of this phenomenon is the technically unjustified appearance of the Gothic arches on wrought iron grills and grates (Figure 19).

While the analyses of cultural impacts are not rare in studies on architectural history, the technical cause is less intensively analyzed. As far as it is also worth attention, the focus of this study is this technological cause.

1. Methodology

In this paper, an attempt is made to analyze the impact of the technology on the shaping of the wrought iron architectural elements. In the first part of the investigation, the development of the iron forging technology is discussed with a focus on detecting the reason behind the development of the various technologies and the consequences of these technologies on the appearance of the artifacts. In the second (evaluation) part of the paper, an attempt is made to demonstrate some general phenomena regarding the interrelation of material, technology, and forms in the field of wrought iron in architecture, especially the origin of the different evolved forms involving the investigation of form and technology-transfer following Istvánfi's work about this kind of transfer tendencies (Istvánfi, 1983; Istvánfi, 2010).

In this research samples of structural and architectural elements (tie-rods, grills, railings, and ironware of doors and windows) of various ages from the medieval time to the 20th century were observed. The analyzed samples stemmed from various European countries: Austria, Croatia, France, Germany, Hungary, and Portugal selected from many photos which were taken by the author on many sites. The features of the samples are analyzed by visual inspection. Some phenomena are demonstrated in the photos of the wrought iron artifacts to highlight characteristics. The phenomena of the fibrous nature of the material is demonstrated on a polished and etched surface of a section taken originally for metallurgical investigations in earlier research.

2. The development of the iron forging technology

Before analyzing the above-mentioned tendencies, it is necessary to investigate the development of the technology, namely the impact of this development on the forging technology and the shaping skill of the craftsmen.

2.1. The beginning of the use of iron

The first iron artifacts were produced from meteoritic iron. The scarcity and the extraterrestrial origin of the material in many cases determined the cultic utilization of the iron objects (e.g., sacrificial dagger, amulet, etc.).

The value of curiosity of iron objects was lost by the proliferation of wrought iron produced from terrestrial kinds of iron ores, mainly bog iron. It was the starting point of the several hundred (thousand) years-long development of iron and steel production technology as well.

2.2. The emergence of wrought iron and forging technology

The first era of the evolution of the smith-craft is the emergence of the iron forging technology which started around the 8–10th century B.C. and lasted up to the 1st millennium A.D.

Initially, the techniques of iron-forging and shaping were based on the earlier developed traditions, knowledge, and manufacturing processes of other metals (technology transfer), namely copper and tin (Johannsen, 1953). The evaluation of the basic procedures, like lengthening, upsetting, splitting, wire drawing, and some decorating/finishing processes like repoussé, metal wire inlaying, or filing was adopted this way (Pereházy, 1986). The shapes of the early iron artifacts were also identical to the typical shapes of the preceding objects made of other metals.

The equipment of the ironsmith workshop was evaluated relatively slowly. Around the 5th century B.C. iron tools and anvils were used universally. The jointing methods of the wrought iron structures, the riveting, the binding, and the smith-welding have been applied since ancient times as well (Pereházy, 1986).

In this first era utility, and functional development had a primal role. The most known iron artifacts are tools, weapons, wall clamps, anchors, wall ties, and parts of different kinds of machinery like siege machines, primitive cranes, or pulleys. Iron was used only in cases in which the characteristics of the material, especially tension strength, meant an advantage. The proliferation of iron in the era can be detected mainly in the field of warfare (Pereházy, 1986).

3. The era of wrought iron in architecture

The expansive application of wrought iron in the field of architecture started at the beginning of the 2nd millennium A.D. This era can be considered the era of the architectural wrought iron, which technically equals the era of the artistically formulated wrought iron in Pereházy's consideration (Pereházy, 1986). This era can be divided into five periods regarding the aspects of manufacturing technology, each of which is separated by the entry of a new determinant technological innovation, namely the emergence of the hammer mill, the spread of the rolled iron wares, the industrial-scale application of cast iron and the revolution of the steel industry in the second half of the 19th century.

3.1. Transitional period (11–13th century)

The first period of the era regarding its level of technical knowledge is rooted in antiquity. The tools are identical to the ones of antiquity, the technical tradition of the smithcraft had been more-or-less uninterrupted since Roman times. The ironsmith of the period possessed the knowledge of basic technological operations and worked with iron (wrought iron) tools on an iron (not steel) anvil. The rounded horn on one side of the anvil, which enabled the easier forming of the curved details of the artifacts, was presumably developed in this period (Figure 1).

Figure 1. Augsburg, a double-horn anvil with a rounded horn (arrow 1) on one side and rectangular horn (arrow 2) on the other

The iron was produced in the melting pit and the bloomery furnace with direct reduction. The iron bloom was purified by a hammer and transformed into bars by the smith in the workshop where it was used for grills, hinges, and other structural or architectural elements.

As far as all elements were prepared manually the products became unique and tool marks, namely traces of hammering on the surfaces of the artifacts, are visual characteristics of the period (Pereházy, 1986) (Figure 2).

Producing commodities from raw materials in the workshop resulted in certain limitations of the size as well. The impact of the technology on the forms can be observed, for instance, in the case of the wrought iron fittings of the Calvinist church gate in Rudabánya (Pereházy, 1982, 1986) or in the case of the door at Meersburg Castle, where the pieces of the metal sheets, which were mounted with horizontal and vertical straps to the door (Figure 3),

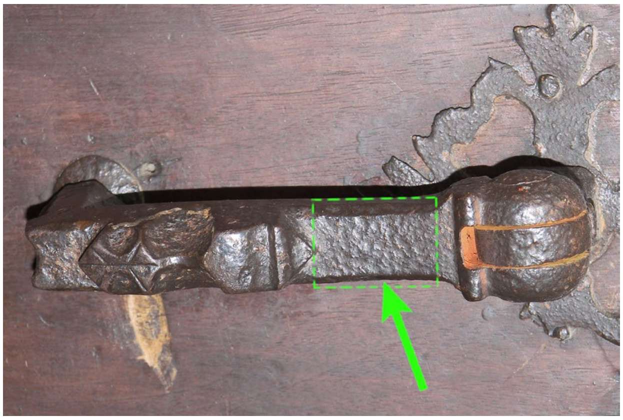

Figure 2. Annecy – wrought iron door handle with tool marks on the surface (marked on the image)

Figure 3. Meersburg Castle, door sash covered by wrought iron – the arrows indicate the vertical (1), and the horizontal (2) straps and the wrought iron plates (3) fixed by the straps

Figure 4. Sibenik – undecorated wrought iron ties – originally placed under the plastered surface

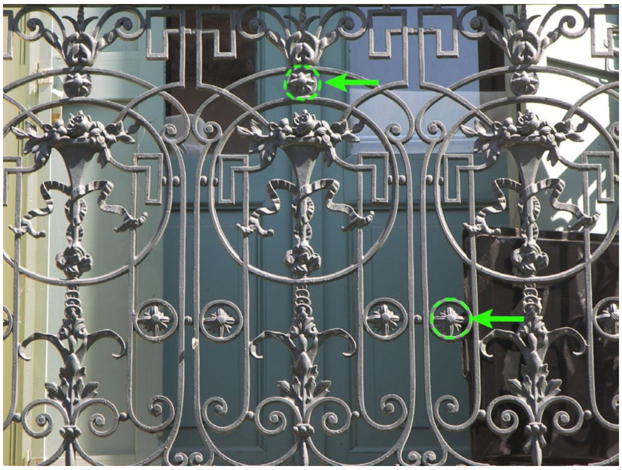

Figure 5. Carcassone – die-prepared, repetitive decoration elements (marked on the image) on a wrought iron railing

were the largest plates which could be produced by the smith in the period.

Up to the end of the Romanic time, the functionality of the form had dominated. The appearance of the objects and architectural elements was determined by the utility claims. All decorations, that appeared on the artifacts of the period, were minor ones and played a subordinate role in the appearance (Pereházy, 1986).

As it was already mentioned, only some of the wrought iron elements were applied on visible surfaces of the buildings, like facades, eaves, windows, doors, etc. A significant part of them was part of structures hidden from the eyes (Figure 4). At the shaping of these inferior structures as a matter of course, the domination of functionality can be observed.

Figure 6. Forchtenstein – a collection of wrought iron spears

3.2. The spread of wrought iron in architecture (13–17th century)

The start of the second period is linked to the emergence and proliferation of the water-driven trip hammers around the 11–14th century in Europe (Pereházy, 1986). In this period the specialization of the former uniform ironsmith profession started (only the bladesmith trade was separated earlier) (Pereházy, 1986). New products appeared on the market of commodities, the craftsmen procured the material in the form of iron plates and bars, consequently, the smith in the workshop was able to focus on the creative part of the work, namely the shaping and the decoration of the artifacts (Pereházy, 1986). The wrought iron under the trip hammer was produced by a similar technology as earlier (hammer cleaning), but the quality was better and the scale was larger, so the separation of the material preparation caused a favorable effect on the elaboration of fine details of the wrought iron objects.

In consequence of the large-scale commodities, for instance, larger surfaces could be covered with one single iron plate, in consequence of the more comfortable circumstances, the previously rudimentary decoration technique was developed to a higher level. In the 13th century, the use of the die on the anvil was a determining novelty (Pereházy, 1986), which had an important impact on the appearance of the wrought iron artifact as far as identical decorative detail elements, like spearheads on grill bars,

Figure 7. Museum of Fine Arts, Budapest. – A wrought iron fence poles shaped as spears

decorated rivet head or other repetitive decoration elements (Figure 5), could be produced in series.

Besides the use of dies, several other decorative techniques were developed too. The carving, etching, chiseling, and piercing techniques appeared in the 14th century, embossing, and damascening which had been applied in antiquity already (at other metals) were applied again on a higher technical level (Pereházy, 1986). This is the first period after antiquity when blacksmiths and ironworkers produced fine mechanical products, like clockworks or repositionable grill structures too.

As far as the use of wrought iron for warfare (Figure 6) preceded the architectural utilization, some forms – mostly in the case of structures, which were designed for defense, like grills, fences, or gates – logically were inherited form from the field of warfare. Common examples are spearheads or shield-like elements. This phenomenon became so popular by the time, that rows of spears were used even centuries later as one basic form of fence (Figure 7).

3.3. The heyday of wrought iron in architecture (17–18th century)

The third period of the development of architectural wrought iron is characterized by the emergence of rolling technology in iron production (Sárádi, 1970; Pereházy, 1986). In the ironworks the iron bars were bundled, forge welded and finely the bundles were rolled. The structure of the material (commodity) was still a fibrous material as it had been earlier, although wrought iron objects lost their rustic appearance, which has been so typical up to this time. The surfaces of the rolled bars and plates were so even, related to the ones which had been used before, that the surface of the fully finished objects was disturbingly spotless (Pereházy, 1986). This new phenomenon was balanced by more and more elaborate decorative work. In the meantime, a second anvil horn was developed too (rectangular or rounded), which enabled more options for the forming of the artifacts. The full repertoire of technological options and knowledge was applicable by the craftsmen yet, that was profoundly harnessed by the great masters of the period. From a technical point of view, the formal virtuosity of the baroque, and later the rococo works, which decoration intended to imitate the plasticity of the natural forms can be considered the climax of the profession (Kühn, 1954; Pereházy, 1986) (Figure 8).

Figure 8. Heiligenkreutz – Baroque gate – the plasticity of the decorative elements can be observed

3.4. The passive period of wrought iron in architecture (19th century)

The formal rationalism of classicism triggered the decadence of the manual forging technology and consequently the ironsmith trade (Pereházy, 1986) (Figure 9). The proliferation of cast iron and the radical propagation

Figure 9. County Hall of Pest County, Budapest, classicist railing with simple decorations

Figure 10. Eisenstadt, winding staircase

of industrialization speed up the process. It also can be mentioned that the appearance of the cast iron products was much more in accordance with the taste of the time than the rustic wrought iron (Campisi & Vinci, 2003). At the end of the 19th century, the use of prefabricated cast iron partially overtook the use of wrought iron technology. However, the wrought iron material did not disappear from the construction industry. As far as the cast iron is lacking relevant tensile strength it was not suitable for all architectural and structural purposes. Chain-bridge or winding staircase (Figure 10) elements (Campisi & Vinci, 2003), and many other engineering structures, which were loaded by tension strength, – at least partially – were produced of wrought iron. In the first decades of the 19th century, wrought iron was used for the railway as well. The homogenous steel material was applied only after the invention and spread of Bessemer, basic Bessemer, and Open-Hearth furnace (Siemens-Martin process) production technologies at the end of the century, which meant the beginning of a new period of technological development as well (Gárdonyi et al., 1959).

3.5. The afterlife of wrought iron in architecture (20–21st century)

The beginning of the fifth period meant the proliferation of industrialized products, consequently the end of the era of craftsmanship and handicraft technologies (Kollár & Vámossy, 1996). The transformation of the iron industry in the second half of the 19th century and the emergence of the good-quality, homogenous iron (mild steel), that changed the fibrous wrought iron material on the markets, were significant changes, but the impacts on the forms of the manually forged iron objects come up nearly a century later only. The reason is complex. On the one hand as a consequence of some contaminations, some early steel materials were rigid and therefore were not suitable for forging. On the other hand, the former material type, namely wrought iron, was still distributed on the market up to World War I (Edvi Illés, 1900; Gordon & Knopf, 2005). The new technical opportunities provided by the homogenous material were realized later only.

The fibrous characteristics of the wrought iron material (Figure 11) had to be considered while shaping for centuries, and the fibrous quality affected the forging techniques too. The disadvantages were well known, as it is summed in the technical literature. The case of fibrous material, in the transversal direction, the yield point is lower, the yield strength is around 10% lower, the ductility and the contraction are approximately 30% lower than in the longitudinal direction (Gárdonyi et al., 1959).

As a consequence of the fibrous characteristics of the material, the wrought iron objects had to be designed so, that the fibers were positioned parallel with the final loads of the finished objects. In the case of objects, which were designed for multidirectional loads, the ironsmith made an effort during the elaboration of the object to apply actions in consequence of which the fibers settle optimally

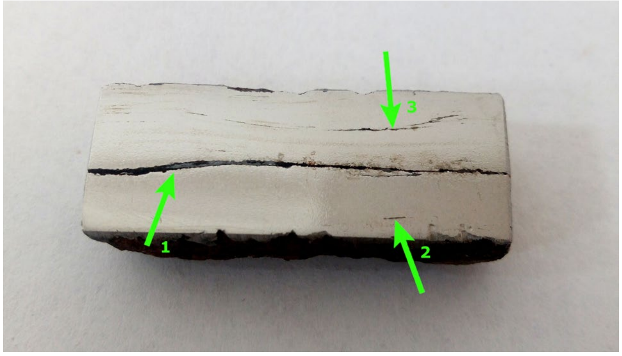

Figure 11. Sample of a wrought iron tie of the Sándor-palace, Budapest. – Traces of a forge-welded joint (arrow 1) and slag inclusions (arrow 2, 3) show the fibrous structure of the material on the etched surface of the sample

Figure 12. Leipzig – typical wrought iron window grill: the composition of bars is the optimal utilization of the fibrous material, that makes easier lengthening (longitudinal transformation) than widening (transversal transformation)

for the loads, like a proper combination of upsetting and drawing and transversal drawing or more often multidirectional element compositions were manufactured like grills (Gárdonyi et al., 1959) (Figure 12).

The modern homogeneous mild steel material enabled new kinds of working methods with much more freedom (Gárdonyi et al., 1959; Kerpely, 1987; Seregi & Seregi, 2002), although it still was not capitalized by the ironsmith for long.

The modern forging technology was mainly developed after World War II because the forging technology was connected to the neo-styles and could not identify itself with the modern approach for a while. The claim for modern forms in the field of architectural wrought iron had

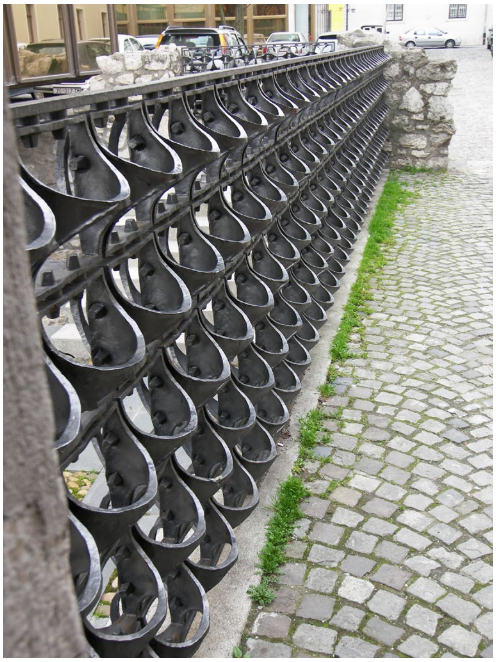

Figure 13. Budapest, Castle of Buda – modern wrought iron railing – harnessing the versatility of the homogenous material regarding the shaping

not emerged until the late 1930s, the decay of the neo-baroque style, which gave great opportunities for wrought iron elements (Pereházy, 1986).

In the fifth era of wrought iron in architecture, new factors emerged which helped to eliminate the earlier so strong interaction of material, technology, and form. At the beginning of the 20th century new jointing techniques like gas welding, and later electric arc welding were invented. These replaced the forge-welding technique; hence, the preparation of the joints became much easier and the connection became more trustable.

Parallel with the rationalization of the architectural forms, similar tendencies can be observed in the field of ironworking too. The iron (mild steel) architectural elements became more and more simple. Simplicity and low fabrication time were the focus. Forging technology was mostly used for monument restorations and in the field of applied arts. The former was responsible for preserving traditional technology the latter possessed with the option of invention, in consequence of which, in the second half of the 20th century a certain kind of revival of the profession could be observed, that finally harnessed the new technical options and advantages of the homogeneous material (Pereházy, 1986; Seregi, 2002) (Figure 13).

4. Evaluation of shaping – the interaction of form and technology embracing eras

As it can be concluded from the historical analyses, basic forms generally were developed as a consequence of technological development, regarding either the material production or the working process of the forging. Initially, this basic form was decorated according to the nature and options of the technological steps. The best ironsmiths in all eras were keen on demonstrating the highest technical knowledge of the era regarding both decoration and structure which endeavor had a significant innovative effect too. During the shaping of the most innovative objects, the ironsmith tried to reach the upper limit of feasibility by challenging the physical reality of the options provided by the material.

At the end of this technical development, the material (quality) and the technology become hindrances to further development unless better material quality or more advanced technology are applied. In the case of such development, the form, which was inherited as a consequence of the customs and the traditions of the trade, does not definitely and consequently reveal the character of the new material or technology as it was revealed in the case of the old ones (Kollár & Vámossy, 1996).

The material and technology usually determine the development of the form in three phases, namely in the evolutional phase, in the phase of continuous development, and in the late phase. In the evolutional phase, the technology has an inspiring effect on the form. In the second phase, during the development, the new formal claims affect the technology, and in the late phase, the physical barriers have an impact on the further development of the trade prompting the tradesmen to abandon something and search for something new. Finally, many times there is a fourth (ultimate) phase too, when the form has an afterlife, as it is applied as a reminder or memento of the earlier times, independently from the original technical circumstances (Kollár & Vámossy, 1996).

Figure 14. Wösendorf – Romanesque wrought iron door hinges (marked by the arrows) are fixing the boards of the door

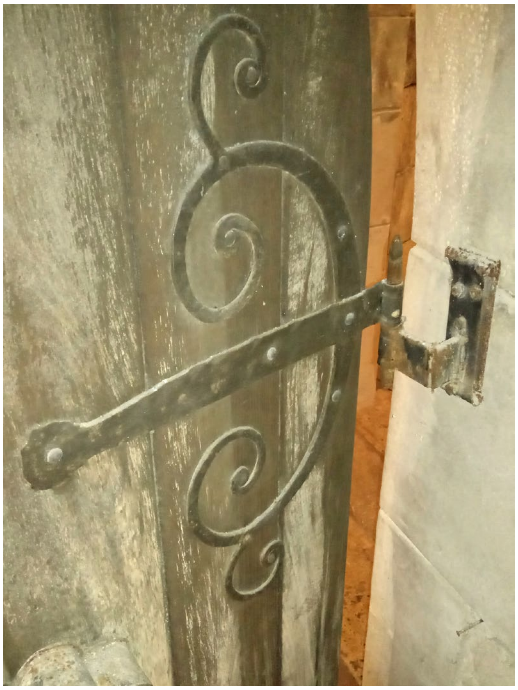

Figure 15. Lockenhouse, castle, late medieval door hinge

Figure 16. Eisenstadt, Esterházy Palace, door hinge on a timber-framed door

The development phases mentioned above can be demonstrated adequately by the development of door hinges. Presumably, the predecessors of the early medieval door gate hinges were the wrought iron chest and coffin bands of the earlier times, like the Longobardi coffin in the Ferdinandeum (Tyrolean State Museum) in Innsbruck, Austria. Medieval doors inherited the way of construction from those chests (Pereházy, 1986) (Figure 14).

The hinges as well as the bands of the chests fastened the boards placed beside each other. A more advanced technical solution is when the hinge is split up into several branches like the original scrollwork hinges of the gate of the Notre Dame in Paris (now it is preserved in a museum, not in situ anymore) (Pereházy, 1986; Campbell, 1997), or in the castle of Lockenhouse (Figure 15), which can be considered as a second phase. This form enables a more elaborate decoration as well.

Later, in the Renaissance, and in the Baroque times the door leaves were constructed of matchboards with frames (Figure 16). The role of the hinges, therefore, was not the fastening of the timber parts anymore, but the suspension of door leaves only, hence those were reduced in size as well, and the focus was on the elaborate decoration.

The ultimate phase can be detected centuries later at the time of Historicism when the hinges on the door imitated the medieval hinge forms but as far as there was no need for fastening the boards of the door leaf they merely applied as decoration (Figure 17).

Figure 17. Erfurt, cathedral – wrought iron is applied as surface decoration only (without real fastening or suspension role)

Another example of the interaction of form and technology is the shaping of the wrought iron objects according to the nature of the fibrous wrought iron. Up to the end of the 19th century, the material of manual forging was fibrous wrought iron (Vidovszky, 2008), which required parallel forming (drawing or upsetting) with the fibers in the material. This phenomenon was analyzed by material scientists in the 19th century, but it was a well-known fact from experience by the ironsmiths in the older times too. The wrought iron grills and rails, – the decoration of which imitated the form of tree branches, twigs, and tendrils, – are typically linear design, which follows the formation of the vegetation, not only visually but regarding the material structure as well, since both the wrought iron material and the vegetal bines has different strength longitudinally and transversally. This similarity of the material structure supports the hypothesis that the reason for the imitation of the natural vegetation forms is not only due to some intuitive decoration urge, but it is a solution of the manufacturer for the application of the wrought iron according to the required purpose on an artistic level (Figure 18).

A special, non-conscious case of form transfer can be detected in the cases of reusing the material. Old weapons were used frequently for the forging of building structures or architectural elements, and building structures were re-forged and reused too for the same or another purpose in other buildings. As far as the production of iron was labor-intensive and the old iron could be relatively easily re-forged, it was a practice of the profession for centuries. In this case, the work on the new object depended on the quality requirements of the new use. In some cases, the object was transformed into iron bars, and the iron bar was used for other objects, sometimes the transformation was minimal, and the shape of the old object can be recognized in the new one (Figure 20). This phenomenon, however, could be the triggering effect of some more conscious form transfer later, when after repetitive subsequent use of some object in a later period not a subsequently used object, but only its shape appears (e.g. a spear or a sword) in a new object's look (e.g. spears in a row as a fence).

Figure 18. Szombathely, St. Elisabeth church – Baroque wrought-iron decoration following the logic of floral growth

Figure 19. Geneva, Saint Pierre Cathedral, the tomb of Henri de Rohan. – Gothic arch in a wrought iron grill – indicated by arrows and dashed line on the image

Figure 20. Carcassone, Window grill made of different wrought iron straps – punched holes (arrow 1) and rivets (arrow 2) without present function, and subsequent welding (arrow 3) give evidence of the secondary use

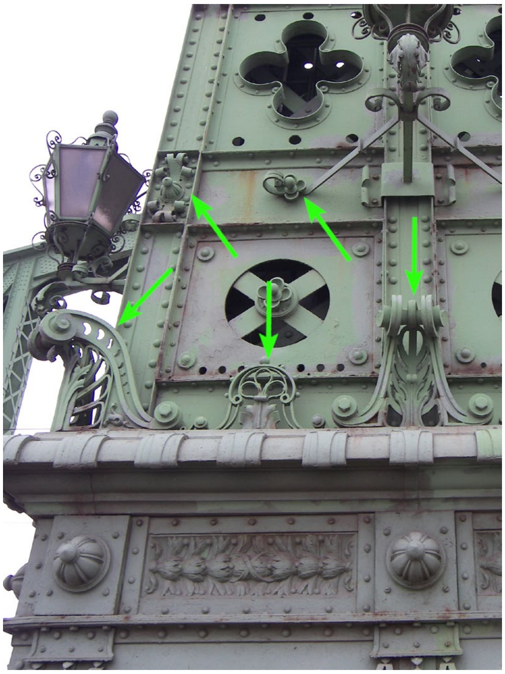

Figure 21. Budapest, Freedom bridge – examples for mass-manufactured wrought iron decoration (marked by the arrows)

The form transfer between two materials of altering nature was already mentioned concerning the Gothic ornamental decoration (Figure 19). The reason for applying formal adaptations was mostly a certain cultural claim for a uniform appearance. Some late occurrences of this tendency are the wrought-iron cornices, capitals, and other moldings in the late 19th century, which were more and more simplified and subordinated to the aspects of the assembly in the last period, as an example of the formal development with the priority of practicability (Figure 21).

Initially, the wrought iron design was adopted for cast-iron architectural elements too. The forms and design are repercussions of the developed forms of the wrought iron structures (form transfer) imitating similar designs, despite the different technology, and structure, and the altering shaping, and joints.

Conclusions

The history of the development of iron forging technology of the architectural elements and the related forms can be divided into five periods. The change between all five periods can be connected to some milestones in the technological development of the production of wrought iron and steel material. A summary can be found in Table 1.

Table 1. The characteristics of wrought iron artifacts in the various periods

Character/ period	11–13th century	>>	13–17th century	>>	17–18th century	>>	19th century	>>	20th–(21st) century
material production technology	melting pit, bloomery furnace (direct reduction)	the emergence of the hammer mill	bloomery furnace (direct reduction) and the first blast furnaces in Europe (indirect reduction), water-driven hammer works	spread of the rolled iron wares	blast furnace, finery, rolling works	the industrial-scale application of cast iron	the former technologies + invention of Bessemer, basic Bessemer, and Open-Hearth furnace (Siemens-Martin process) production	revolution of the steel industry	Bessemer, basic Bessemer, and Open-Hearth furnace production
typical material types	iron bloom was purified and transformed into wrought iron bars in the workshop (limited in size)		the former types + iron plates and bars produced in hammers works (larger scale, higher quality)		the former types + rolled bars and plates with even surfaces (no rustic appearance)		the former types + mild steel (in the last decades)		good-quality, homogenous mild steel
manufacturing technology	tools and techniques of antiquity, basic forging operations, riveting and forge welding at the joints, simple iron anvil		specialization of ironsmith craft, advancement of shaping and decoration techniques, use of the die on the anvil		a second anvil horn was developed (rectangular or rounded), a full repertoire of technological options and knowledge		decadence of the manual forging technology as a consequence of the spread of cast iron and industrialization		new technical opportunities provided by the homogenous material (more freedom), new jointing techniques: gas welding, electric arc welding (more trustable joints, lower fabrication time)

End of Table 1

Character/ period	11–13th century	>>	13–17th century	>>	17–18th century	>>	19th century	>>	20th–(21st) century
shaping features	functionality of the form had dominated, unique artifacts with tool marks, (traces of hammering) on the surfaces, production of structural or architectural elements (e.g. grills, hinges)		repetitive decoration elements (by the application of the die), advanced embossing, and damascening techniques, appearance of carving, etching, chiseling, and piercing techniques, fine mechanical products (e.g. clockworks, repositionable grills)		even more elaborate surface decoration work, formal virtuosity, and plasticity likewise to natural forms (baroque, rococo)		formal rationalism (classicism), engineering structures (chain bridge, railway) and functional use (winding staircase), neo-styles (in the second half of the period) with "mass-manufactured" decorations		traditional forms of smithcraft (neo-baroque, monument restorations) + modern forms, harnessing new technical options (applied arts)
phenomena regardless of the era	cultural form transfer, subsequent use, formal change as a consequence of the development of techniques, and the change of the functional role (e.g. types of hinges)								

Both the basic forms of the wrought iron compositions and the development of the decorations were determined by the characteristics of the material for nearly three thousand years. An interesting consequence of these facts is when the new, homogenous mild steel material appeared at the end of the 19th century. The traditional forms and design approach were so strong in the profession, that it lasted for decades until – in the second half of the 20th century – the better characteristics of the new material type were harnessed in the field of the forming.

Regarding the wrought iron elements in case of restoration, it is important to understand, the characteristics of the material, the design, and production methods for the proper, competent preservation actions.

In case of a need for changing elements in the historic structures – even if the replacement material will be different – the shaping and the forming of the new elements should be according to the logic of the historic material and structure.

In this study, wrought iron was analyzed, but the methodology for analyzing the interrelation between the form and the technology can be used in the case of investigating other historical technologies.

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