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The Valuation of Aesthetic Preferences and Consequences for Urban Transport Infrastructures

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Abstract: The importance of transport infrastructure for individual well-being and regional economic development and growth, but also its adverse side-effects, make a comprehensive assessment of the general appropriateness of new construction and rebuild indispensable. Assessments, however, often lack certain issues. For instance, aesthetic aspects are usually not part of the (economic) evaluation of large infrastructure projects, albeit individuals may be (positively or negatively) affected by the aesthetic 'value' of infrastructures. This paper proposes the aesthetic index developed by Birkhoff as a method to quantify the aesthetic impact of buildings/facilities in urban areas. To test the basic applicability of the index for transport infrastructure facilities, we apply it at first to airport terminals in Germany. We also test the suitability of the index to derive the willingness to pay for aesthetic exterior design—since market prices are easy to obtain with respect to hotel room rates—using hotel architecture as the first example. Regression results of a hedonic price model indicate a significant relationship, suggesting the basic suitability of the index to uncover consumers' willingness to pay for an aesthetic outward appearance. We suggest further research to test the suitability of Birkhoff's index for general urban transport infrastructures in order to derive utility-based welfare measures toward aesthetic issues. For highly controversial urban (overground) infrastructures, we propose the inclusion of an aesthetic component in cost–benefit analysis.

Keywords: aesthetics; aesthetic measurement; Birkhoff index; hedonic price analysis

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1. Introduction

As mobility needs in society increase, so too does the need for new and modern transport infrastructure utilities. The importance of transport infrastructure for individual well-being, regional economic development and growth, but also its adverse side-effects, make a comprehensive assessment of the general appropriateness of new construction and rebuild indispensable. In most cases, project assessment takes place by means of cost–benefit analysis, in which all relevant costs and benefits of a project are evaluated and aggregated to a single (monetary) unit. Such assessments, however, often lack certain issues [1]. For instance, aesthetic aspects are usually not part of the (economic) evaluation of large infrastructure projects, albeit individuals may be (positively or negatively) affected by the aesthetic 'value' of infrastructures.

Importantly, despite the manifold potential benefits associated with new infrastructures (e.g., travel time savings, better accessibility), they often evoke opposition along with a lack of acceptance by citizens [2]. Recent examples of new infrastructure construction plans, such as the new railway connection between Torino and Lyon (Susa Valley—Italy), the new railway station in Stuttgart (Germany) show how sensible citizens oppose such plans. A prominent example is a relatively new road bridge in Dresden, Germany (the so-called Waldschlösschen bridge). Construction plans led to severe opposition, protests, court hearings and finally to a referendum. The result of the referendum was (albeit narrow) in favor of the construction, but, as a consequence of this, the city of Dresden ultimately lost its world cultural heritage status by the UNESCO in 2009. Obviously, aesthetic issues—an essential factor for the status—were not part of an initial project appraisal. However, they should be part of a comprehensive evaluation process, because side-effects of aesthetic issues, such as the loss of the cultural heritage status, may be closely related to economic losses through a reduction in tourism [3,4]. However, how can we measure aesthetics and do individuals attach some monetary value to aesthetic issues such that they can be part of an economic project appraisal?

The present study seeks to answer these questions. The paper proposes the aesthetic index developed by Birkhoff [5] as a method to quantify the aesthetic impact of buildings/facilities in urban areas. The index makes use of geometrical properties of the facility in question and, thus, is based upon objective criteria. To test the basic applicability of the index for transport infrastructure facilities, we firstly apply the index to airport terminals and, in addition, we test its suitability to derive the willingness to pay estimates (and thus the possibility to include such measurements in cost–benefit analyses) for hotel architecture since market prices are easy to obtain for hotel markets. The regression results of a hedonic price model indicate a significant relationship, suggesting that consumers are willing to pay higher prices for an aesthetic outward appearance. We suggest further research to test the suitability of Birkhoff's index for further urban transport infrastructures in order to derive utility-based welfare measures for aesthetic issues. For highly controversial urban infrastructures, we propose the inclusion of an esthetic component in cost–benefit analysis.

2. Theoretical Insights—Measuring the Aesthetic Value

The term esthetic was already known in the ancient world and originates from the Greek term "aisthētikos", from "aisthēta" (perceptible things), from "aisthesthai" (perceive) [6]. The translation already indicates that the ancient philosophy just knew the term aesthetic in the sense of perception but not in the sense of theory concerned with beauty as it became popular some centuries later [7] (p. 14), [8] (p. 1).

In the 18th century, Alexander Gottlieb Baumgarten, a German philosopher, began to establish aesthetics as a philosophical science for the first time. In his work Esthetica (1750–1758) he established the new systematic and philosophical thinking about aesthetics and defined it as a philosophical explanation of beauty and art. Sesemann [8] (p. 2) points out that Baumgarten defined aesthetics as being "the act of consciousness that perceives an object, at the same time evaluates it and recognizes its aesthetic value". For the first time, Baumgarten introduced terms such as sensation, feeling and taste in connection with beauty and aesthetic theory [9] (p. 255).

Many other well-known philosophers, e.g., Johann Gottfried Herder, David Hume, Immanuel Kant, and Friedrich Schiller mentioned the issue of aesthetics in their works in the following years. Nevertheless, their theories contradicted each other such that many different conceptions of beauty existed.

The contradictory views on taste development and sensual perception in connection with beauty become obvious when comparing two of the most famous philosophers of the 18th century: Immanuel Kant and David Hume.

Hume claims in his work ´Of the Standard of Taste' (1757) that beauty is the expression of the subject's aesthetic preference and not the result of an object's characteristics. Beauty is exposed to subjectivism and always "lies in the eye of the beholder" [7] (pp. 13–14), [10]. At the same time, he explains that humans do not possess taste congenitally but that it is possible for everyone to acquire taste through experience, practice, and comparison. Following Hume's notion, it is important to consider the opinion of experts when it comes to the judgment of aesthetics and beauty [11].

Kant countered Baumgarten's and Hume's theory with his work 'Kritik der Urteilskraft [Critique of Judgment]' (1790) in which he emphasized that humans generally possess an aesthetic power of judgment. Therefore, Kant's notion "Beautiful is what is generally liked without definition" implies that beauty possesses a certain level of generality and, as a result, it is important to consider the average taste of people instead of looking at individuals [11].

Note that since we are interested in building architecture, we refrain from discussing product design literature (e.g., [12–15]), yet all these approaches have common elements with our approach in Section 3.

In economics, the measurement and valuation of aesthetics is rather underexplored [16]. The authors of [17] discuss the economist's perspective for a sector, which is very close to the aesthetics, notably for the arts. Since, however, they deal with tradable goods (such as paintings) or art utilities, which are in general priced (e.g., museums, operas), we refrain from discussing this topic in more detail. The reason for this is that this paper centers on transport infrastructure utilities. Their aesthetical effects may be regarded an externality (positive of negative is not clear), for which there exists no market. We therefore need non-market goods valuation methods.

From the economist's point of view, such methods are often used in transport economics. We therefore refer to a conventional approach when a method tries to find out whether individuals are willing to pay any money for a certain aesthetical view, thereby implying the existence of substitution (respectively, the existence of an indifference curve) between aesthetics and money.

Contingent valuation is a survey method in which individuals may directly express their monetary valuation for certain objects, or landscapes or buildings. Although this method is severely criticized [18–20], it enjoys (due to its simplicity) great popularity. With respect to the aesthetics of transport infrastructure utilities, the authors of [11] used this method to study the aesthetical effects of the controversially debated "Waldschlösschen" bridge in Dresden, where the bridge construction led to the loss of the UNESCO world heritage status for the city of Dresden. Their findings suggest that monetized aesthetical gains may be high enough to finance the cost difference for the construction of other infrastructure alternatives (such as tunnels) which do not intervene in the valley landscape and therefore may be regarded as more aesthetic.

In urban areas, a great variety of architecture can be recognized. Almost every building seems to have a different story and reflects the ideas and ideals of different periods of time as well as the views of the architects involved in the planning and construction process. At the same time, they have different levels of attraction for people. Especially historical buildings are often perceived as being highly aesthetic and beautiful and even worth travelling to and paying money for [21], thereby indicating a relationship between aesthetics and architecture [9,22].

The advent of the hedonic pricing models (HPM) [23] brought a breakthrough for the consideration of architectural and aesthetic issues in economics. Assuming (among others) perfect information and no transaction cost, the hedonic approach treats the price p of a differentiated good (such as houses or apartments) as a function of its attributes z, i.e., $p = p(z)$ where $z = z_1, z_2, \ldots z_k$ denotes the attribute vector of the object (e.g., apartment) in question.

A view in the literature reveals that several hedonic approach contributions have empirically analyzed the impact of architecture in general and even to some extent the aesthetics of architecture, in particular on real estate prices (e.g., [24–30]). In-depth overviews are provided by [30,31]. All of these studies capture the aesthetic value of real estates in different ways. The authors of [28] used officially designated landmark and architectural award information in order to analyze office prices in downtown Chicago. The authors of [26,32] constructed indices out of expert's surveys (architects) in order to analyze the impact of aesthetics on the prices of office buildings for Cambridge, Boston and Tel Aviv. The authors of [25,33] captured aesthetic effects in their studies by introducing parameters for the different architectonic styles in their hedonic price equations. A similar approach was also used in [25], where the authors analyzed the price effects of small historic buildings. The authors of [34] defined several different criteria for new urbanism to analyze its impact on house prices in Portland. The authors of [27] evaluated the impact of historic houses on real estate prices. Some studies have incorporated the aesthetic impact indirectly in their analyses. For instance, the analyses in [35,36] (both studies analyze the impact of noise on house prices) used variables for view, respectively, the construction period of the buildings to control for aesthetic effects.

Due to their microeconomic foundation, discrete choice models (see e.g., [37]) have become a common research instrument, especially in transport economics. Meanwhile, discrete choice models are used not only for mode, route or airport/airline choices but also in order to evaluate aesthetical preferences. An interesting choice experiment in this respect has been performed in Ireland [38,39], where the authors, by use of photographs in choice experiments, could derive spatially distributed willingness to pay measures for several landscape improvements.

In an experimental approach, [40] used bidding experiments and addressed the theoretical problems in the economic valuation of aesthetical preferences (mainly associated with divergences between the equivalent and the compensating variation and the aggregation of individual bids).

In addition to the economic perspective, landscape architecture provides some interesting approaches to measure the aesthetic value. Such methods result mainly in index numbers, i.e., different objects or landscapes are ordered according to their index value. Index approaches can be roughly subdivided into descriptive inventory methods and quantitative holistic models [41]. Such methods largely reflect Hume's notion of standard taste mentioned before. This more or less implies that groups of experts or committees have the ability to judge aesthetic values better than individuals due to the experience and exercise of their members on aesthetic issues.

Descriptive inventory methods (e.g., bipolar semantic list or uniqueness ratio) define certain criteria for aesthetics and note their existence (or non-existence) for the objects to be evaluated. In some cases, they assign values to the beauty-relevant components. Finally, the (weighted) components may be aggregated to a single index value, which allows comparisons among various objects.

In quantitative holistic models (such as scenic beauty estimation or the law of the comparative judgment), the physical aesthetic criteria from descriptive inventory methods are combined with individual psychological cognitive criteria and are therefore extended by surveys.

3. The Birkhoff Index

An interesting alternative approach of measuring the aesthetic value of an object is provided by the American mathematician David George Birkhoff, who wrote four essays (1928–1932) about the problem of the perception of aesthetic objects such as works of art, spoken lyrics and musical compositions, and tried to find an empirical way to compare them [9] (p. 265). In the end, Birkhoff summarized his findings and presented a formula for the mathematical measurement of esthetics in his work 'Esthetic Measure' [3].

At the beginning of his work, Birkhoff points out that aesthetics as a science is mainly concerned with aesthetic feeling and the aesthetic object leading to this feeling. Birkhoff at first divides aesthetic objects into two broad categories, notably natural objects and artificially created objects. Those belonging to the first category are usually created without intention and can be found in nature (e.g., landscape, sunsets), whereas objects from the second category are created with intention and, therefore, express the ideas and ideals of the creator (e.g., works of art, architecture) [3] (p. 3). Birkhoff's measurement approach considers only objects of the second category and just looks at "the formal side of art", i.e., the visible, exterior (mostly) geometric characteristics of an object (e.g., contour of a building, shape of an object) [3] (p. 13). Thus, this approach seems at first glance to fit well with the scope of our study. Transport infrastructure and buildings belong to the second group of objects as they represent the ideas of the architect and can be evaluated by looking not only at the functional but also at the visible and exterior attributes.

The functionality of the human brain is essential for aesthetic judgments. Birkhoff, therefore, defines a three-step process that takes place in the human brain when an esthetic experience is made [3] (p. 3). This process is illustrated in Figure 1.

Figure 1. Process in the human brain while an aesthetic object is being observed. Source: own depiction based on Birkhoff [3] (p. 3f.).

The first stage comprises an initial effort of attention needed for the perception of an object, varying proportionally with the level of complexity (*C*) of an object. The higher the complexity (*C*), the higher the initial effort needed. In the next step, the brain rewards this effort with a "feeling of value", which is expressed as aesthetic measure (*M*). Finally, "a realization that the object is characterized by a certain harmony, symmetry, or order (*O*)" takes place and represents the last stage within an aesthetic experience process [3] (p. 3f.).

For this reason, the aesthetic value (*M*) is composed of these two key elements: complexity (*C*), order (*O*). It is given by:

$$M = \frac{O}{C} \tag{1}$$

The complexity (*C*) refers to the effort of attention needed for the perception of an aesthetic object; it thus refers to the object's composition. Every part of an object, i.e., every contour of the polygon, causes the eye to move and accordingly increases the effort involved. Consequently, Birkhoff defines *C* as being "the number of indefinitely extended straight lines which contain all the sides of the polygon" [3] (p. 34).

According to [3], "The property of an aesthetic object which corresponds to any association will be called an 'element of order in the object'" (p. 9). This means that the order (*O*) results from the geometrical relationships between subcomponents of an object, which can be subdivided into the following elements of order:

- *V* = vertical symmetry;
- *E* = equilibrium;
- *R* = rotational symmetry;
- *HV* = relation to a horizontal-vertical network;
- *T* = characteristic tangents;
- *S* = similarity;
- *F* = unsatisfactory form.

Inserting these elements in Equation (1) yields:

$$M = \frac{V + E + R + HV + S + T - F}{C} \tag{2}$$

V takes the value 1 if the respective object possesses vertical symmetry and 0 if it does not. If an object has vertical symmetry, it is perceived as especially comfortable and favorable from the observer as he or she has the impression that it is in equilibrium.

This is why *E* equals 1 for objects that possess vertical symmetry (*V* = 1) or have a horizontal base and thus are in complete optical equilibrium. If a polygon is in ordinary mechanical equilibrium, it just takes the value 0, as it is less aesthetically appealing. For polygons without equilibrium, *E* equals -1.

The rotational symmetry (*R*) obtains the value 1 if the polygon possesses *V* = 1, and 0 if it has no symmetry. Generally, *R* is computed by q/2, where q denotes the number of partial symmetric polygons. *R* cannot be greater than 3 [3] (pp. 35–39).

If all sides of a polygon lie in a horizontal–vertical network, i.e., if the polygon has no diagonals but just vertical and horizontal lines, HV gets the value 2. HV equals 1 if there are some sides that do not fulfill this requirement or if there is a diagonal in the polygon. All other cases are evaluated with $HV = 0$ [3] (pp. 39–41).

The two order elements—similarity (S) and characteristic tangents (T)—find their application when it comes to, e.g., ornaments and curvilinear elements. As they can be found in the design of polygons such as buildings, which play an important role in this work, the two elements are added and considered in the evaluation. If a similarity of type exists, S receives the value 1; if there is more than one, it is assigned the value 2. In the case that there is no similarity, S equals 0. Design elements such as circles, curvatures, ellipses or parables are captured through their characteristic tangents (T). Their number equals the value of T with the exception that parallel tangents are only counted once. If the object does not contain curvilinear elements, T equals 0 [3] (pp. 57 ff.).

The unsatisfactory form (F) is an element of order that can have a negative influence on the aesthetic measure (M). If all of the above conditions are fulfilled, F equals 0 and has no negative influence on M. If one condition is not met, F equals 1, and if more than one condition is missed, F equals 2 [3] (pp. 41–42).

The maximum of the aesthetic value M can be reached if the order (O) reaches its highest positive value, whereas the complexity (C) approaches its possible minimum value: $M^{max} = \frac{O^{max}}{C^{min}}$. The relation $DU = \frac{M}{M^{max}}$ thereby gives the degree of utilization of the aesthetic potential.

One main advantage of Birkhoff's approach is that all geometric features contributing to the aesthetic value of an object are combined to a single index. In addition, recent contributions from neuroaesthetics seem to confirm the significance of the geometrical dimensions used by Birkhoff. The authors of [42] (pp. 276–285) conducted an experiment in which they analyzed how the characteristics of an object (e.g., symmetry, complexity, geometrical shapes, order) affect the brain activities during the aesthetic experience of people looking at and judging about this object. Their findings support that the aesthetic judgment is mainly ruled by symmetry and order. In addition, this study identified complexity as being also a characteristic of aesthetic but not as important as symmetry and order. In general, a series of studies in neuroscience and psychology identify the importance of symmetry, order and complexity for aesthetic judgment [43–46]. Another advantage is that the index measures aesthetic objectively, thereby avoiding biased evaluations stemming from behavioral anomalies which have been found to distort the decisions of economic agents, even with respect to transport-related decisions [47,48].

These findings support the use of Birkhoff's approach in our paper. Birkhoff assumes that symmetry as an element of order is very important for the aesthetic value of an object and that, in particular, vertical symmetry is perceived as especially comfortable by the beholder. This is in line with the neurological findings.

On the other hand, it should be noted that in Birkhoff's approach, materials (e.g., glass, steel etc.) or colors are not part of the aesthetic value. We thus keep in mind that Birkhoff's formula may not capture all possible factors, which contribute to the aesthetic value of an object. In addition, it seems that Birkhoff's formula underestimates the uniqueness or even the reputation of the creator of the object in question. Take, for instance, a painting by a famous artist, for which potential buyers are willing to pay a lot of money in an auction, or for which the public is willing to pay a certain entrance fee to a museum. A (very good) copy of this painting by another unknown artist would certainly achieve a much lower price in an auction, or people would be willing to pay much lower entrance fees to a museum in order to be able to enjoy the copy. The aesthetic value assigned by the Birkhoff approach would, however, be the same for the copy and the original painting. Furthermore, the surrounding area is not considered in the formula but may play an important role in the process of aesthetic perception. It influences the beholder to a great extent according to the architect Richard Neutra (as cited in [9] (p. 109)). Moreover, buildings are often very complex objects, especially older ones. With increasing complexity, it becomes more and more difficult and time-consuming to capture all geometric elements and to define the components in a reliable and correct way. If there is a very high level of complexity, every indefinitely extended straight line and diagonal needs to be counted, which bears a great potential for errors. With rapidly increasing complexity, the aesthetic value automatically decreases as well, which might be misleading when considering the results of the neurological findings mentioned above that suggest that complexity is not always automatically perceived as unaesthetic by the beholder.

Accounting for the advantages and keeping the disadvantages in mind, in the empirical part, we will proceed with the calculation of Birkhoff's index, using German airport terminals as an example.

4. Empirical Implementation: Birkhoff's Aesthetical Value for German Airport Terminals

We now empirically calculate the Birkhoff index for nine German airport terminals. Airport terminals are typical transport infrastructure utilities in urban areas. In addition, they seem to fit with the main idea of this paper relating architecture to an aesthetical value. Furthermore, airport capacity expansion seems, in many cases, to lack acceptability (mostly due to noise-related issues). The (new) Munich airport, for instance, reached a total construction time of 28 years, where most of this time was court hearings. We thus conclude that the consideration of airport terminals is a good example for the scope of this paper. In total, we have considered the following cases:

- Berlin Brandenburg "Willy Brandt" Airport;
- Cologne/Bonn Airport
- Dresden International Airport;
- Erfurt-Weimar Airport;
- Frankfurt Airport;
- Hamburg Airport;
- Hannover-Langenhagen Airport;
- Leipzig/Halle Airport;
- Munich "Franz Josef Strauß" Airport.

The calculations consider only the respective airport terminal. For airports with more than one terminal, two separate calculations have been performed and the arithmetic mean of all terminals is computed. All results are rounded to two decimal places.

Color photos are the basis for the evaluation, which show the airport terminals in front view. During the selection of the pictures, it is important that all buildings have the same perspective (front view) and that the terminals are completely pictured to make them comparable.

In the following, in order to save space, we present computations for "Dresden International Airport". The airport started its operations in 1935. In 1998, the terminal was rebuilt within three years. Since 2001, the terminal building has been located in a former hangar of the GDR aircraft industry. The exterior view shows contemporary architecture with glass front sides, metal lamination and brick-red ceramic tiles. Based on Figure 2, Table 1 presents all numerical values of several relevant variables:

Table 1. Birkhoff values for Dresden International Airport. Source: own calculations.

C	*V*	*E*	*R*	*HV*	*S*	*T*	*F*
12	1	1	1	1	1	0	1

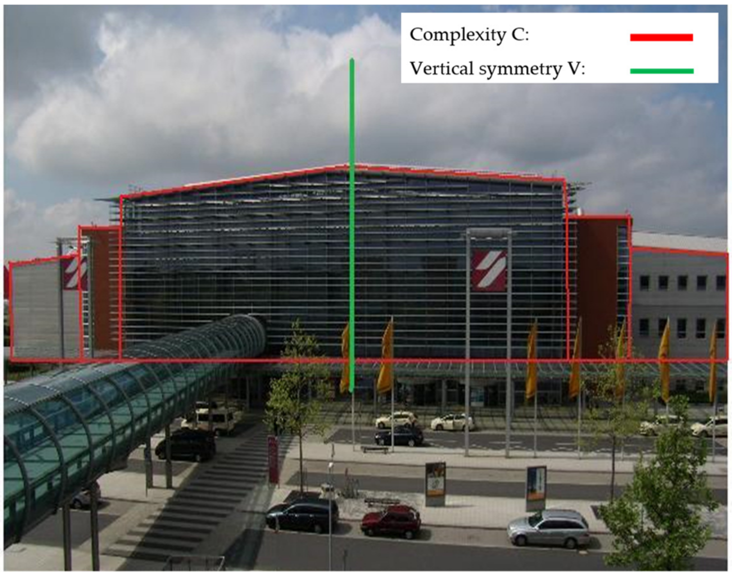

Figure 2. Dresden International Airport Terminal. Source: own photography.

The red lines in Figure 1 represent complexity C. This variable is defined as the number of infinitely extended lines that contain all sides of the polygon, as described above. Therefore, C takes the value of 12. The vertical symmetry axis is marked as a green straight line in the photography. Therefore, V = 1, the terminal building is in equilibrium and E is assigned the value 1. The rotational symmetry R received the value 1 because of the central symmetry of the terminal. HV = 1, because not all sides of the building would fit into a horizontal–vertical network. The parts of the building that are on the right and left side are similar to each other, so S = 1. T an F are both 0, because the front view of the terminal does not include characteristic tangents (T) and there is no unsatisfactory shape (F).

Plugging these values in Equation (2) gives the aesthetic result for "Dresden International Airport":

$$M_{DRS} = \frac{1+1+1+1+1+0-1}{12} \approx 0.33 \tag{3}$$

For the calculation of the maximum aesthetic utilization of the terminal (Equation (3)), we consider the maximum sum of the order O. O^{max} is the result of the addition of the highest values of several components, which are defined as the order O. As already mentioned, O^{max} takes the value of 9. C has the same value as in the calculation above (C = 12) and Equation (3) becomes:

$$M^{max} = \frac{O^{max}}{C} \approx 0.75 \tag{4}$$

The ratio of M and M^{max} gives the utilization of aesthetic potential, which is in our case 0.44 or 44 percent.

Table 2 summarizes the results of all considered airport terminals. The airports are ranked according to the aesthetic measure M.

Table 2 shows that Frankfurt Airport is the most aesthetical (rank 1) airport among the considered airport terminals according to the Birkhoff approach. By contrast, Cologne/Bonn Airport terminal has the lowest aesthetical value (rank 9).

In addition, Frankfurt (together with Erfurt/Weimar and Hamburg) mostly utilizes its aesthetical potential, whereas, Cologne/Bonn Airport has the lowest utilization of aesthetic potential. An interesting result was found for Erfurt/Weimar airport, a rather small sized airport located in East Germany. According to our measurements, this airport takes rank two and therefore has the second most aesthetic airport terminal in Germany. Besides, the new Berlin Brandenburg Airport performs rather below average.

Table 2. Total results of the Birkhoff approach. Source: own calculations.

	Airport	M	M^{max}	Utilization (in %)
1.	Frankfurt	0.86	1.30	67
2.	Erfurt/Weimar	0.75	1.13	67
3.	Hamburg	0.67	1.00	67
4.	Munich "Franz Josef Strauß"	0.65	1.13	61
5.	Hannover-Langenhagen	0.63	1.14	56
6.	Berlin Brandenburg "Willy Brandt"	0.45	0.82	56
7.	Dresden International	0.33	0.75	44
8.	Leipzig/Halle	0.25	0.52	49
9.	Cologne/Bonn	0.066	0.14	48

Albeit the weaknesses of the Birkhoff approach discussed in the previous section, we see clearly that it is basically possible to compute and evaluate the aesthetics of transport infrastructure. Nonetheless, the question remains of whether it is possible to attach an economic value to it, suitable for welfare analysis in the sense of cost–benefit analysis. For this reason, it is necessary to apply methods of non-market valuation. As transport infrastructure utilities have no market prices, a direct use of hedonic pricing for infrastructures is not possible, leaving choice modeling approaches as the only possibility to test the economic suitability of the Birkoff approach.

However, in order to gain a first impression, we made use of the hotel market. More specifically, we computed the Birkhoff value for several hotels around Bonn/Germany and fed these values into a hedonic pricing model. Hedonic pricing has been intensively applied in the past in the tourism industry. Related studies have utilized price information on package tours [49–53] or of room rates [54–60] in order to construct and estimate hedonic price equations, where vectors with room characteristics, hotel attributes, and locational attributes enter the analysis.

Although the evaluation of intangible aspects of tourism such as hotel brands has been gaining increasing attention in recent years and presents a foundation for the investigation of architectural influences [61] (p. 187), to the best of the authors knowledge, hotel architecture and its impact on room rates has not yet been analyzed in the literature.

The whole procedure, analysis and results are described in Appendix A. Therein, we found a positive and significant impact of the exterior design, respectively, hotel architecture (measured by the Birkhoff index) on hotel room rates. This indicates a basic applicability of the Birkhoff index in order to derive the willingness to pay for architecture.

5. Discussion and Conclusions

Motivated by a potentially increasing public acceptability of new transport infrastructure utilities via better aesthetic appearance, this paper presented and discussed a simple index—the Birkhoff index—for aesthetical measurement. Subsequently, we applied the Birkhoff index to airport terminals in Germany. We also tested the basic applicability of the Birkhoff index to derive the willingness to pay for exterior design of hotel buildings using market prices for hotel bookings. Our findings support the hypothesis that consumers may attach value to aesthetics. We were able to identify a significant relationship between esthetics and room rates.

Nonetheless, the conceptual construction of the Birkhoff index seems to have some shortcomings. First, it only takes into account the geometry of the building in question and ignores further factors that could be of importance for aesthetics, such as colors, materials and the surroundings. Consequently, not all possible aesthetic effects are captured by the approach. Second, the Birkhoff index ignores further dimensions of objects such as uniqueness or the reputation of the creator.

According to our findings, aesthetics should no longer be only a subject of philosophy but also one of practical significance for business and policy. Generalizing our results to all consumers, we can therefore conclude that in particular for highly contested new transport infrastructure projects a higher-valued aesthetic appearance will certainly increase individual utility and possibly also public acceptability. Unfortunately, current project appraisals (e.g., cost–benefit analysis) for public infrastructure usually does not include an aesthetic component. Such aesthetic components might, however, alter the results of cost–benefit analyses. Occasionally, economists suggested the consideration of an aesthetic component in project assessment methods, in particular for highly controversial infrastructure. For instance, [11] found that for the case of the "Waldschlösschenbrücke" in the city of Dresden (Germany), citizens may have a willingness to pay high enough to finance the difference of the current to a more aesthetic and also more expensive bridge appearance. Such smart policy is in our view in a position to enhance public acceptability.

As the Birkhoff formula offers an easy, understandable and objective way to assess aesthetics and to compare aesthetic values for different projects, we suggest its further use or even its extension in order to account for the unsettled factors mentioned above.

The hedonic approach for aesthetic valuation that we performed in our paper applies only for cases where market prices exist. Since for infrastructure market prices are usually not available, we carried out our calculations for hotel buildings as a first attempt to attach a monetary value to aesthetics, measured by the Birkhoff index. However, computing willingness to pay measures in the case of transport infrastructure requires the use of choice modelling approaches. As [38,39,62] show, it is possible to apply choice experiments in order to evaluate the aesthetic appearance of landscapes. We thus suggest the inclusion of the Birkhoff index in adequate choices experiments for urban transport infrastructure in order to derive utility-based welfare measures that can be part of cost–benefit analysis. Moreover, because aesthetic issues might also be a matter of concern for other transport facilities, e.g., public transport stations or even whole systems [63], dealing not only with buildings in the narrow sense could be appropriate as well.

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Appendix A. Empirical Test of the Applicability of the Birkhoff Index to Derive the Willingness to Pay for Exterior Design

In our analysis, we used photos of 31 different hotels in the greater area of Bonn (taken from the frontal perspective of the hotel entrance). In the following, we illustrate the procedure relying on the example of the Maritim Hotel Bonn. First of all, it is necessary to edit the hotel pictures by sketching all geometric forms being part of the Birkhoff formula and that are visually ascertainable (see Figure A1).

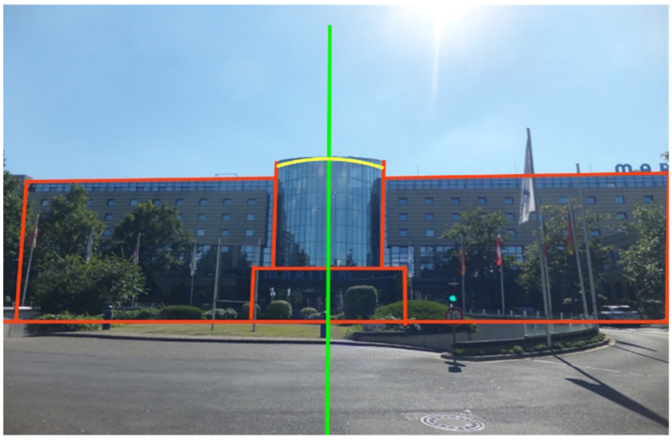

Figure A1. Front view of the Maritim Hotel Bonn with the visually ascertainable components of the Birkhoff formula. Source: own depiction.

Inserting these insights in Equation (2), we obtain the result in Table A1.

Table A1. Aesthetic evaluation of the Maritim Hotel Bonn using the Birkhoff formula. Source: own computation.

	C	*V*	*E*	*R*	*HV*	*F*	*S*	*T*	*O*	*M*	*DU*
Maritim Hotel Bonn	10	1	1	1	2	0	2	1	8	0.80	80%
Max	10	1	1	3	2	0	2	1	10	1.00	

To attain the value of *C*, it is necessary to add up all indefinitely extended straight lines, which are displayed in red, as well as all diagonals (only if applicable). In this example, the complexity *C* reaches a value of 10.

The determination of *O* is as follows: the Maritim Hotel Bonn shows vertical symmetry and a horizontal base. The green line divides the picture into two halves, which are perfectly identical. This is why *V* obtains the maximum value that can be achieved in this category, notably 1. This characteristic supports the fact that the building is in complete optical equilibrium and has rotational symmetry. Both categories, therefore, reach the values 1 and 2, respectively. All lines of the object are lying on a horizontal–vertical network and no diagonals can be found; thus, *HV* equals 2. As all previous conditions are fulfilled, the building shows a satisfactory form and *F* (unsatisfactory form) is assigned the value 0 and has no negative impact on the result of the formula. Due to the fact that both sides of the building consist of the exact same components and accordingly show a high degree of similarity, *S* takes the value 2. In the last step, all design elements of the building that include circles, curvatures or something similar (yellow in this case) are added up, leading to the value of *T* (here 1).

Consequently, the respective building utilizes 80 percent of its aesthetic potential, which is a rather high value. With this result, the hotel is rank three of all 31 analyzed hotels. In conclusion, the Maritim Hotel Bonn can be classified as aesthetic with elements of order such as vertical symmetry that seem to be especially comfortable and favorable in the eye of the beholder.

Subsequently, we apply Birkhoff's formula to all 31 hotels in the wider area of Bonn. The results can be found in Table A2.

Table A2. Results of the Birkhoff formula. Source: own computations.

	Hotel	M	M^{max}	DU in %		Hotel	M	M^{max}	DU in %
1	Ringhotel Rheinhotel Dreesen	0.52	0.62	85	17	Dorint Venusberg Bonn	0.09	0.23	40%
2	Hilton Bonn	0.27	0.38	70%	18	Hotel My Poppelsdorf	0.44	0.63	70%
3	Sternhotel Bonn	0.33	0.44	75%	19	Das Boutique Hotel—Villa Godesberg	0.22	0.78	29%
4	Hotel Collegium Leoninum	0.64	0.91	70%	20	ibis Bonn	0.44	0.63	70%
5	V-Hotel	0.33	1.11	30%	21	Mercure Bonn Hardtberg	0.00	0.28	0%
6	Maritim Hotel Bonn	0.80	1.00	80%	22	Villa Esplanade	0.64	0.91	70%
7	Kameha Grand Bonn	4.00	5.00	80%	23	Best Western Hotel Kaiserhof	1.00	1.60	63%
8	Ameron Hotel Königshof	0.11	0.56	20%	24	President Hotel	0.08	0.15	50%
9	Günnewig Hotel Residence	0.13	0.26	50%	25	Hotel Baden	0.86	1.43	60%
10	Hotel Zum Löwen	0.46	0.64	72%	26	Galerie Design Hotel Bonn, managed by Maritim Hotels	0.04	0.38	10%
11	Hotel Zur Post	0.75	1.17	64%	27	B&B Hotel Bonn	1.40	2.00	70%
12	Steigenberger Grandhotel Petersberg	0.08	0.40	20%	28	Hotel Bonn City	1.75	2.50	70%
13	InterCityHotel Bonn	1.17	1.67	70%	29	Hotel Krone	0.36	0.79	45%
14	Hotel Garni Deutsches Haus	0.67	1.11	60%	30	Rheinhotel Loreley - Superior	0.23	0.51	44%
15	Best Western Hotel Domicil	0.67	0.80	83%	31	Maritim Hotel Königswinter	0.06	0.30	20%
16	Hotel Continental	0.09	0.29	30%					

On average, the analyzed hotels have a mean aesthetic value of $\overline{M} = 0.6$ as well as a mean aesthetic potential $\overline{M}_{Max} = 0.95$. Both show rather large standard deviations ($s_M = 0.76$ and $s_{M_{Max}} = 0.93$) indicating that hotels vary considerably when it comes to aesthetic value and potential. The highest results are reached by the Kameha Grand Hotel Bonn with a value of $M = 4$ and $M_{Max} = 5$. Additionally, the Intercity Hotel Bonn, the Maritim Hotel Bonn, and the B&B Hotel show very high values for M and M_{Max}. The reason for these hotels achieving such high numbers might be the fact that their architecture is characterized by low complexity and high order. At the same time, hotels such as the Steigenberger Grandhotel, the Mercure Bonn, the President Hotel and the Galerie Design Hotel Bonn are characterized by an architecture that is very high in complexity but relatively low in order. These observations reflect the assumption of Birkhoff that the aesthetic measure (M) reaches its maximum if the order (O) reaches its highest positive value and the complexity (C) approaches zero at the same time.

In addition, we can observe that in many cases the buildings of hotel chains are the ones with the lowest utilization of aesthetic potential. This might be due to the fact that they are relatively new and were built under other aesthetic ideals, which are nowadays characterized by simplicity and ease, modern designs without many design elements in the form of ornaments.

In general, the considered hotel buildings all have a horizontal base, but the upper contours usually are not straight and include many complex elements and a great variety of forms, which is the reason why the rotational symmetry often just reaches low values. A lot of hotels have entrances that are separated from the central building, which directly causes higher complexity and distorts vertical symmetry. This automatically has a negative impact on the result of the formula and decreases the aesthetic value. Additionally, many of the old buildings have numerous different design elements and complex architecture, which directly increases complexity, often destroys symmetry and thus decreases the aesthetic value. This is in contrast to the new and modern hotels, such as, for example, the Kameha Grand, which was opened in 2009 and has an architecture that is limited to basics and characterized by simplicity, as already mentioned.

As already mentioned, the hedonic approach uses market prices in order to construct and estimate a hedonic price equation. It assumes mainly perfect information, no transaction cost and the existence of market equilibria. The hotel industry comes fairly close to fulfilling these preconditions. For example, considering perfectly informed participants, hotel guests are nowadays well-informed through the internet. Detailed information on the hotels including services and amenities as well as reviews of the property are usually available, thereby offering the guest the chance for well-prepared choices. Modern revenue management systems, which aim at maximizing the hotel occupancy, are used to establish market equilibrium.

Hedonic prices are determined by estimating a *hedonic price function* (HPF). The HPM assumes that a product z consists of n different characteristics z_i measuring the quantity of the characteristic i ($i = 1, 2, \ldots, n$). This can be expressed by the vector $z = (z_1, z_2, \ldots, z_n)$. Consequently, the price of a product z results from its implicit or hedonic prices and can be defined as the hedonic price function $p(z) = p(z_1, z_2, \ldots, z_n)$. The functional form (mostly linear, exponential or logarithmic) and the quantitative dependency between the price and the considered attributes is not clear from theory but estimated empirically instead. The partial derivative of the HPF with respect to the single attributes allows computing the marginal willingness to pay (*MWTP*) for a single attribute z_i.

$$Hedonic\ Price\ or\ MWTP_i:\ h_i = \frac{\partial p(z)}{\partial z_i},\ i = 1, 2, \ldots, \text{n}. \tag{A1}$$

Data involve information for a total of 47 hotel attributes for 31 hotels in the wider area of Bonn/Germany. Table A3 shows these attributes and their scale of measurement. The data involve prices collected from booking.com for one or two overnights, single or double room and for five- or two-weeks booking prior to the guest's arrival. We do this in order to control for the number of overnights, the type of room and the time of booking, which can possibly distort the estimated implicit prices.

One may argue that, in particular, locational factors (which are decisive for room rates) may be an indirect indicator for the aesthetic value of the hotel in question. Certainly, locational factors may reflect the attractiveness of the hotel surroundings, such as certain monuments, historic places, central business districts or even nice views, but they do not reflect the architectural aesthetic value of the hotel itself. We therefore see no contradiction in using both factors together in our analysis.

First of all, the mean price differences between one or two nights are the biggest ones regardless of one or two guests staying or booking two or five weeks prior to arrival. For instance, the mean price for one PAX for one night in Bonn five weeks before arrival lies at €102.67, whereas the mean price for two PAX under the same conditions is about €22 higher. As expected, the lowest mean price of €102.67 can be found for one PAX, one night and five weeks before arrival; the highest mean price of €247.74 is charged for two PAX staying two nights and booking only two weeks before arrival.

Most hotels belong to the four-star category (18 out of 31), which is why the mean star rating has a value of $\overline{x} = 3.65$. Comparing the means of stars and customer ratings on booking.com, it is striking that all respective hotels achieve high values in the customer ratings. The overall mean rating is $\overline{x} = 8.2$ points, where 10 is the highest value that can be achieved. The mean room size of all hotel categories is $\overline{x} = 20.47$ sqm, whereas the mean size rises according to the star ratings, so five-star properties offer on average bigger rooms than two-star hotels. Looking at the straight-line distance, the mean distance between the hotels and railway station is $\overline{x} = 3.35$ km, whereas the mean distance to the airport is $\overline{x} = 18.24$ km. On average, 61.3% of the hotels included belong to a hotel chain such as Maritim, Dorint, or Hilton, whereas the remaining 38.7% are private ones.

In order to test the robustness of our results with respect to the aesthetic values, we specify three different regression models: a linear, a semi-logarithmic and a double-logarithmic model. For the linear model of the form $Y = b_0 + b_1x_1 + \ldots + b_nx_n + e$, the parameter estimate b_i represents the hedonic price of a hotel attribute (in €). For the semi-logarithmic model specification $\ln Y = b_0 + b_1x_1 + \ldots + b_nx_n + e$, the regression coefficient represents a semi-elasticity. Finally, for the double-logarithmic model specification of the form $\ln Y = b_0 + b_1 \ln x_1 + \ldots + b_n \ln x_n + e$, the regression coefficient is to be interpreted as an elasticity.

Since preliminary Breusch–Pagan tests indicated heteroscedastic variances of error terms, Table A3 shows the regression results using OLS with White's heteroscedasticity robust standard errors. In particular, with respect to the aesthetic value, preliminary tests showed that models using the degree of the utilization of the aesthetic potential (DU) seem to perform best.

Table A3. Regression results. Source: own calculations.

	Linear Model		Log-Linear Model		Log-Log Model	
	Estimate	**Standard Error**	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**
Const	−512.55	47.391 ***	0.8968	0.233 ***	0.1082	0.331
WeeksBeforeArrival	−1.1217	1.181	−0.0052	0.005	−0.0048	0.005
PAX	23.0189	3.754 ***	0.1389	0.018 ***	0.1374	0.018 ***
Nights	109.262	3.506 ***	0.6729	0.016 ***	0.6729	0.016 ***
FreeCancellation	3.7067	3.779	0.0344	0.019 *	0.0385	0.019 **
BreakfastIncluded	34.2313	5.043 ***	0.2101	0.025 ***	0.1924	0.026 ***
Restaurant	18.8609	5.222 ***	0.1328	0.027 ***	0.1070	0.026 ***
LanguagesSpoken	−0.1991	1.711	−0.0008	0.009	0.0078	0.009
ShuttleService	38.6629	6.527 ***	0.2081	0.029 ***	0.1975	0.025 ***
FacilitiesforDisabledGuests	3.4906	4.870	0.0290	0.026	0.0080	0.026
FreeWifi	10.2793	6.380	0.0885	0.027 ***	0.0714	0.027 ***
AirConditioning	26.278	6.244 ***	0.1406	0.028 ***	0.1293	0.028 ***
ConferenceSpace	21.2546	4.906 ***	0.1339	0.025 ***	0.1623	0.025 ***
SizeSqm	2.65769	0.362 ***	0.01583	0.002 ***	0.0161	0.002 ***
CustomerRating	31.7595	6.506 ***	0.1876	0.029 ***	0.1642	0.029 ***
DistAir	5.7831	2.247 **	0.0355	0.011 ***		
Log_DistAir					0.5419	0.118 ***
DistSt	−4.6239	2.135 **	−0.0283	0.011 ***		
Log_DistSt					−0.0625	0.016 ***
Aesthetic Potential	6.4531	3.509 *	0.0210	0.013	0.0300	0.013 **
Adjusted R^2	0.7757		0.8496		0.8536	

*** Significance level of 99%, ** significance level of 95%, * significance level of 90%.

As we can observe in Table A3, the signs of parameter estimates do not change within the different model specifications. In addition, parameter estimates between the semi- and double-logarithmic model are very similar. We thus consider our results as robust.

In general, all three models show a high fit documented by the adjusted R^2. The semi-logarithmic and the double-logarithmic model perform similarly in terms of the goodness of fit. We, therefore, discussed estimation results in more detail for the semi-logarithmic model, which is also mainly used in the literature cited above. Nevertheless, we compared the results with those of the other two models. Note that for binary variables, the semi-elasticity is computed $e^{b_i} - 1$ [64] (p. 474f.). In the following, we use this formula for binary variables. Variance inflation factors (VIF) are sufficiently low in the final models, giving no indication for multicollinearity.

Hotels in Bonn can increase their prices by 95.99% for an extension from one overnight to two. At the same time, they can only charge 14.9% higher prices for one additional PAX (reference is one person). This is also supported by the linear model, which again has the highest coefficient for the number of nights. As this model indicates the amount of money that people are willing to pay more for an additional unit of an attribute, it shows that hotels can charge 109.26€ more for one extra night but only 23€ more for one additional guest. Furthermore, people are willing to pay around 23.38% more if breakfast is included in the price (respectively, 21.22% more in the double-logarithmic model or 34.23€ more in the linear model). Another mark-up in the price is charged if a shuttle service is available, which becomes clear in all three estimated models.

Additionally, customers seem to place high importance on online ratings achieved by hotels in Bonn on booking.com. On average, they are willing to pay 31.76€ more for one more rating point. This shows that platforms such as booking.com, holidaycheck, and TripAdvisor gain high importance in the hotel industry and that hotels that receive good reviews can increase their revenues, as people are willing to pay more based on the experiences of other guests.

Moreover, the considered hotels can charge premium prices for a free cancellation option, for the availability of a restaurant, for free Wi-Fi services, for air conditioning and for the availability of conference space. When it comes to the hotel room size, one additional square meter causes the price to increase by 2.66€.

Surprisingly, the number of weeks before arrival, as well as the number of languages spoken and facilities for disabled people offered in a hotel show no significant impact on prices. Apparently, hotels in the wider area of Bonn do not extensively practice revenue management and, in addition, guests do not pay much attention to the number of languages spoken by the hotel staff (possibly because they perceive this to be a fundamental feature of the hotel) and the existence of facilities for disabled persons.

Referring to the location of hotels in Bonn, it is clear that the lower the straight-line distance to Bonn Hbf is, the higher the prices that can be charged (4.62€ per km). The respective elasticity is 0.062% per 1% decrease in distance to the station. The linear distance to the airport CGN, however, shows some interesting and at the same time puzzling results. As we can observe, in all three models, this parameter estimate is positive, meaning that the higher the distance to the airport the higher the room rate. We offer two possible explanations for this. First, as we analyze hotels in the wider area of Bonn, those ones closer to the airport are at the same time farther away from the city center. Thus, it could be that the distance to the central station (or city center) is in reality somehow non-linear and increasing in prices. Thus, the positive parameter possibly captures the additional effect of the distance to the city center rather than the initially intended effect of the airport as a major infrastructure facility. Second, hotels in the south of Bonn (a much higher distance to the airport) often have nicer locations close to the river Rhine or are generally closer to nature than hotels near to the airport and thus are in a position to charge higher rates. All in all, we consider these results unsurprising and in line with the existing empirical literature on hedonic prices for hotels.

As for the impact of hotel architecture on room rates, we found a mixed picture. In the double logarithmic model, the esthetic potential of the hotel architecture is significant at the 95% significance level. This means that hotels can charge more if they have special and appealing architecture and thus a high aesthetic potential. Looking at the semi-logarithmic model, the parameter estimate is not significant; nonetheless, the p-value is very close to 0.10. In the linear model, people are willing to pay on average 6.45€ more per unit of aesthetic potential at a significance level of 90%. When the results of all three models are taken into account, we find suggestive first evidence that an increasing aesthetic potential in hotel architecture in the sense of Birkhoff corresponds to higher room rates, thereby indicating a willingness to pay for exterior design.

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