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Analysis of airport configuration and passenger behaviour

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Abstract

Airports serve a variety of services related to both the preparation of the passengers for their air trip and their free time inside the terminal. Hence, the process of airport planning is complex and strongly case-specific because of the big variety of services that airports might offer. Based on these premises, this paper aims at analysing airport space configuration, considering the Theory of the Social Logic of Space (space syntax). It is assumed that a morphological investigation can shed light on pedestrian movements and choices enabling planners to propose more pedestrian-friendly terminals.

The study explores the positional relationships between the aeronautical (e.g. check-in and security) and non-aeronautical services (e.g. retail services, beverage areas and lounge), taking into consideration the Lisbon Portela international airport case (the departure floor, in the check-in area before the security control zone). Space syntax is applied to analyse and evaluate the building plan and its implications on passenger perceptions and choices. Visibility Graph Analysis is developed and the variables: visual connectivity, visual integration (global and local), intelligibility and synergy of the terminal are compared to assess airport planning and space allocation.

The configurational findings are faced with a survey conducted to collect data on passenger perceptions and choices. The frequency of usage of the non-aeronautical areas is estimated and passenger characteristics related to their personal profile, travel choices and activities inside the building contribute to the assessment of the terminal configuration through the use of Discrete Choice Modelling.

The major conclusion of this paper is that the attempt to include SS indicators in DCM was rewarding since the initial assumption that SS affects passenger choices was proved through the significance of the equivalent variables that were included in the developed model. It was shown that SS can stimulate passenger choices and favour alternatives that are more accessible or well-connected.

Keywords

Airport terminal planning, passenger movements, passenger activities, discrete choice models, space syntax.

1. Introduction and background

Airports provide a variety of activities related to both the preparation of the passengers for their air trip and their free time inside the terminal. Three broad categories of airport activity types can be identified: essential operational services, traffic-handling services and commercial services (Doganis, 1996). In-between these activities, the passengers have to find their way between different areas; they are often in a hurry and must avoid getting lost. This can be a difficult task since airport terminals are often characterized by confusion and disorientation (Seidel, 1982; Brown, 2001), they do not have a generic shape and are designed/organized in several ways. Besides that, many passengers are first-time users, not used to the particular space and fast motion (Raubal, 1997), they also come from different cultural backgrounds, speak different languages, are often late, nervous and out of focus (Mollerup, 2000/2001).

Passengers' activities which are not related to their air-trip can vary and might range from shops to personal well-being centres. Nowadays, many airports regard such services as alternative sources of revenues. Depending on the airport type (hub, low cost, business etc.), the diversity of the available activities differs and the time that the passengers spend on them varies. Hence, the airport planning process is complex and strongly case-specific because of the big variety of services one intends to offer.

Based on these premises, the objective of this paper is to analyse airport space configuration and relate it to passenger choices before reach the security zones. It is assumed that space configurational analysis can shed light on pedestrian movements inside the terminals and modelling passenger choices can enable planners to propose more pedestrian-friendly airports.

Configuration is defined not simply as the set of connections in a built space system, but as the "relations that take into account other relations" (Hillier, 1996). Hence, emphasis should be given on the positional relationships between the aeronautical (e.g. check-in and security) and non-aeronautical services (e.g. retail services, beverage areas and lounge). Lisbon Portela international airport is used as a case study (the departures floor, where the check-in and the security control take place, is studied in this paper) and space syntax (SS) techniques are applied to explore the terminal plan and its implications on passenger perceptions and choices.

Visibility Graph Analysis (Turner, 2007) is used and the variables connectivity, integration (global and local), intelligibility and synergy were estimated to assess airport planning and space allocation. In order to compare configuration and perception, a survey was conducted to collect data on passenger characteristics, perceptions and choices (with an emphasis on beverage zones). The frequency of usage of the non-aeronautical areas is estimated and passenger characteristics are related to their personal profile, travel choices and activities inside the building.

In the airport environment where the passengers need to perform specific, obligatory, sequential activities related to their trip and where they have the chance to perform discretionary activities, SS can be included in other computational tools and reveal interesting findings from a managerial perspective. For this reason, in this paper it is intended to explore the potential of SS to be included in the structure of *Discrete Choice Modelling* in order to explain passenger behaviour and choices. In particular the objective is to test the impact of SS on passenger choices over the beverage places located before the security control.

The paper is organized in five sessions. After the introduction, the case studies in which space syntax was included in mathematical models are presented. The third session deals with the methodological approach, presenting SS basic features, the survey conducted in the research and the applied DCM strategies. Before the conclusions, results and the corresponding discussion are developed. The main conclusion of the paper is that SS can add value in explaining passenger choices.

2. Literature review: space syntax in modelling

Space syntax has been applied in studies related to the design and planning of pedestrian facilities in both urban and indoor pedestrian environments. In Kalakou and Moura (2014), SS contribution in planning indoor pedestrian facilities has been discussed and research problems, addressed with SS and other tools have also been outlined.

In relation to shopping districts, Sarma (2006) showed that shopping choices are affected by configuration, according to SS variables. Regarding transport facilities, the route choices inside the multi-layered Shibuya metro station were found to be affected by one's visual range, the number of turns and the shortest distances (Ueno et al. 2009). Kawada, Yamada and Kishimoto (2014) tried to explain though a Multinomial Nested Logit model the street choices of people. The distance, the moving direction of streets and the type of behaviour (planned or spontaneous) were designated as influential factors. The built space configuration, analysed by means of potential accessibility, affected more the choices of men, of people who were walking alone and those who had no defined destination.

SS linear model (“axial maps”) has been found to adequately represent human movement patterns (Turner & Penn, 1999) and evaluate space configuration (Hillier & Penn, 2004). In retail, Ortiz and Hillier (2007) found that better integrated streets are more likely to attract retail activities on them.

At the urban level, Lee and Seo (2013) found that configuration potential accessibility was significantly associated with pedestrian volumes through a multivariate regression model that was built with SS indicators and GIS-based variables for the city of Seoul. In the same vein, the activity levels and the corresponding pedestrian movement patterns in the area of Galata, Istanbul/Turkey, were analysed by Özer and Kubat (2007). SS and a multi-regression analysis designated the factors that play an important role in the prediction of activity levels: the sense of safety, space accessibility and land-use patterns.

Özbil (2013), after comparing different model structures, concluded that when including both connectivity and land-use to explain pedestrian movements in an area, the model explains better the pedestrian movements. Interesting findings were also presented by Scoppa and Peponis (2015) who analysed the connectivity of the streets of Buenos Aires in relation to the distribution of commercial frontage.

In other modelling applications, Hoeven and Nes (2014) aimed to improve the wayfinding, orientation and visibility of two metro stations in Brussels by using SS in to the process of station reconfiguration. In financial terms, Hillier (1996) first introduced the concept of “movement economies” and since then researchers attempt to monetize space configurations. Recently, Enström and Netzell (2008) developed a translog hedonic regression model and provided some evidence that SS can contribute to explaining office rent rates in a city.

Following the same concept, Chiaradia et al. (2013) explained variations in residential property values in London through a hedonic model that included SS indicators and property characteristics. Finally, real-estate assessments were also found to benefit by the inclusion of SS indicators in financial models (Law, Stonor and Lingawi, 2013).

3. Methodological background

The shape of a transport building can be assessed in three directions: function (spaces internal connections and movement efficiency), psychology (all aspects related to the user’s experience of a space beginning including safety and comfort) and structure (construction overall quality, flexibility and sustainability) (Durmisevic and Sariyildiz 2001). This study focuses on the airport building functional features, intending to explore space syntax potential (Hillier and Hanson, 1984) to be included in the structure of *Discrete Choice Modelling* – DCMs in order to explain passenger behaviour and choices.

Space syntax theory and application

Space syntax is a theory and a set of methods about space, reflecting both the objectivity of space and our intuitive engagement with it (Hillier, 2005). More and more scientists and practitioners are using it in design as an evaluation tool, as described in the literature review session. It has the potential to a) analyse the space configuration in both qualitative and quantitative terms, b) represent and c) quantify the built environment performance.

Under this perspective, the characteristics of the built space are comprehended as independent variables which affect, for instance, the pedestrian behavioural patterns (Penn, 2003). The focus is to investigate "movement", here considered the *ethos* of the built space liveability and dynamic. Hillier succinctly explained the principles that support the approach: "We move linearly, interact in convex space, and experience space as "isovists" (Benedikt, 1979) with a convex core and more linear spikes". In order to quantify the movement, SS software used in this research (depthmapX) measures the flows in a given built space based on the configurational principle. The analysis considers three types of distance: metric, topological and geometric (Hillier et al., 1993).

Assuming these distinguished ways to explore distance, Depthmap© calculates two important syntactic measures: a) integration, which measures how close each system element (modelled as a line, a point or a polygon, according to the chosen technique) is to all the others (to-movement) and b) choice, which calculates how many distance-minimizing paths between every pair of element each element lies on (through-movement).

Hillier et al. (2012) explained that "integration represents the to-movement potential of a space, and choice the through-movement potential, pointing out also that the two measures correspond to the two basic elements in any trip: selecting a destination from an origin (integration), and choosing a route, namely the spaces to pass through between origin and destination (choice)". Taking into account such comprehension, the corresponding built space maps can be modelled. Under the metric distance assumption, a map with the shortest paths can be produced.

Based on the previous information and the literature review, the Lisbon airport terminal plan is investigated according to the VGA perspective (Visibility Graph Analysis, considering the point feature based on the isovists or visual fields). Four variables are explored: visual connectivity, visual integration (global and local), intelligibility and synergy.

The visual connectivity consists of the number of direct visual connections among the system elements. Regarding visual integration, two types are distinguished: global and local. The first one considers the integration of all system elements in relation to all the others (radius n) and the latter one restricts the calculation to elements that are up to three visual connection (visual steps) away from each other (radius 3).

The degree to which the visual integration and visual connectivity measures correlate is defined as the intelligibility of the system. The degree to which the global and the local visual integration correlate is defined as the synergy of the system. When an area is found to have low values of both connectivity and integration, then it is assumed that it is difficult to be reached. When relating these measures, the intelligibility of the system is estimated expressing "the degree to which what can be seen and experienced locally in the system allows the large–scale system to be learnt without conscious efforts" (Hillier, 1996).

Discrete choice modelling

Discrete Choice Models (DCM) are used to explain a decision maker's choice over a defined set of alternatives. The aim is to use attributes of the different alternatives, characteristics of the decision-maker or interactions of these factors in order to explain the choice process. The logit model and the nested logit model are commonly used in applications.

The concept of utility is introduced to express the benefits that the decision maker gains from the choice of the specific alternative. The deterministic utility of an alternative "i" for an individual "n" is expressed as the sum of the deterministic utility and a random component "ε_{in}" that captures the errors in the model due to several sources, such as unobserved alternative attributes, unobserved individual characteristics, measurement errors and proxy variables (Ben-Akiva & Lerman, 1985):

$$U_{in} = V_{in} + \varepsilon_{in}$$

Different types of variables can be used, such as generic for all the alternatives, specific for some of the alternatives or socioeconomic which are related to the decision makers' characteristics.

The probability (P_{in}) of a decision-maker "n" to choose an alternative "i", over a set of alternatives "Cn" is given by the formula:

$$P_{in} = \frac{e^{V_{in}}}{\sum_j e^{V_{jn}}}$$

In order to assess the actual impact of the variables in the choices of individuals, different specifications can be tested. For each of them the parameters are estimated by maximum likelihood, and various statistical tests are applied to assess the quality of the specification.

In this paper, a DCM will be presented for the choices of the passengers over 4 different alternatives, considering the beverage services areas inside an airport. Biogeme (Bierlaire, 2003) was used for the estimation of the model.

4. Results and discussion: Lisbon airport case study application

Lisbon Portela airport is the biggest airport of Portugal. It has two runways and two terminals, reaching the total number of 18 million passengers in 2014.

The analysis considered the departures floor (Figure 1), where the check-in and the security control take place. In the plan under study there are short stairs which connect different levels: in order to simplify the modelling, and because of the minimum variation, all the floor was assumed as having a same level.

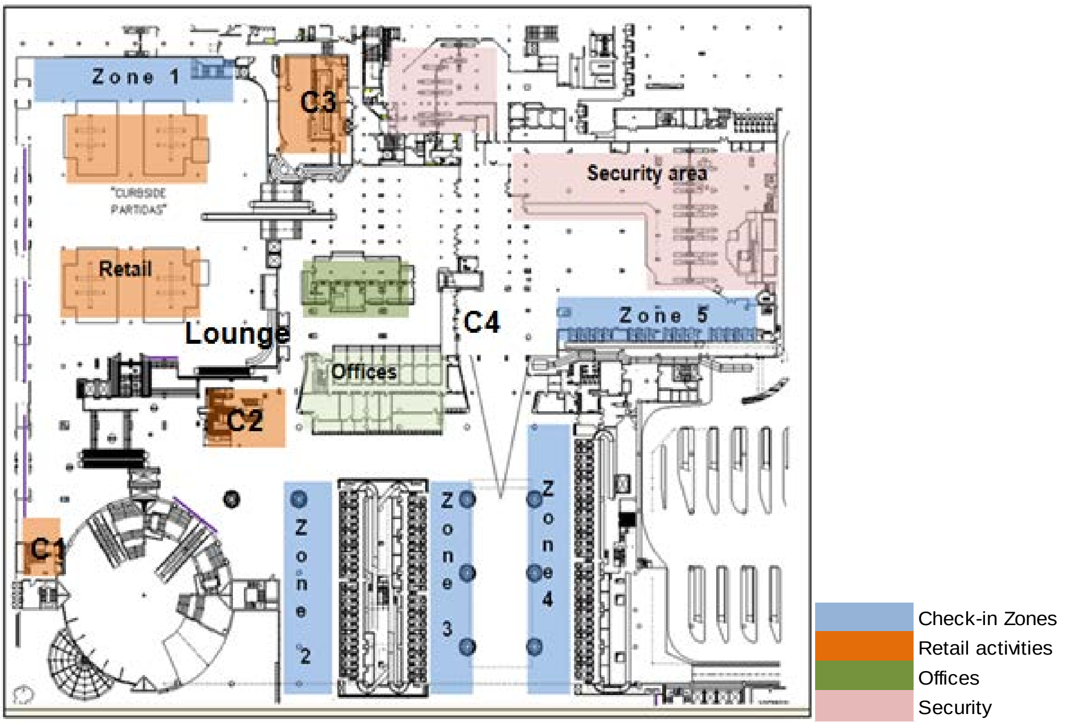

Figure 1: Departures floor layout

Space syntax variables

Figures 2, 3 and 4 present respectively the values of visual connectivity, global (Rn) and local visual integration (R3) of each point of the building, modelled according to the Visibility Graph Analysis technique. Red-coloured areas demonstrate high integration and good connectivity, while blue-coloured areas are very segregated and poorly-connected.

The space where the check-in counters and the security control are located (here named as aeronautical zones) present low values in both the visual connectivity and the visual integration maps. On the contrary, the main corridors leading to these areas are characterized as highly connected and integrated. Considering the time pressure under which the passengers act, this result is positive for the positioning of the moving corridors inside the building. Good values for the corridors connecting the entrances to the check-in and from the check-in to the security control area compensate the low values of the aeronautical areas. In practice, under this configuration, good signage can support the given connection to and from the check-in and security zones.

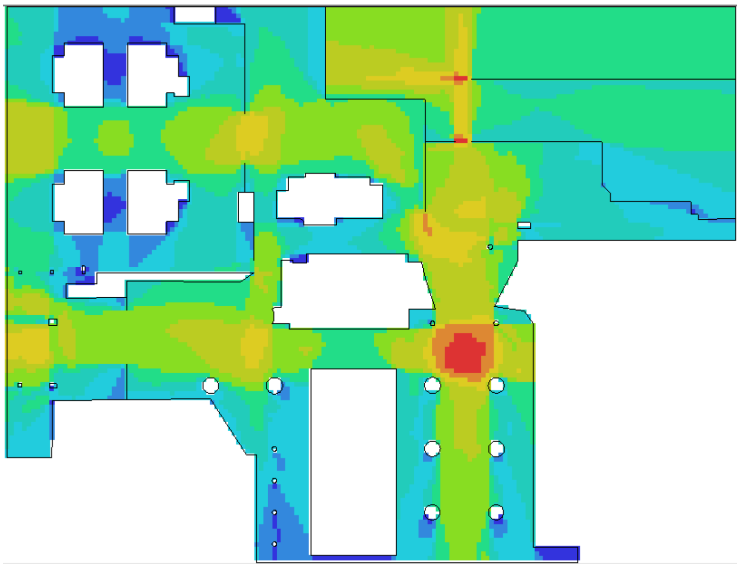

Figure 2: Connectivity map (VGA).

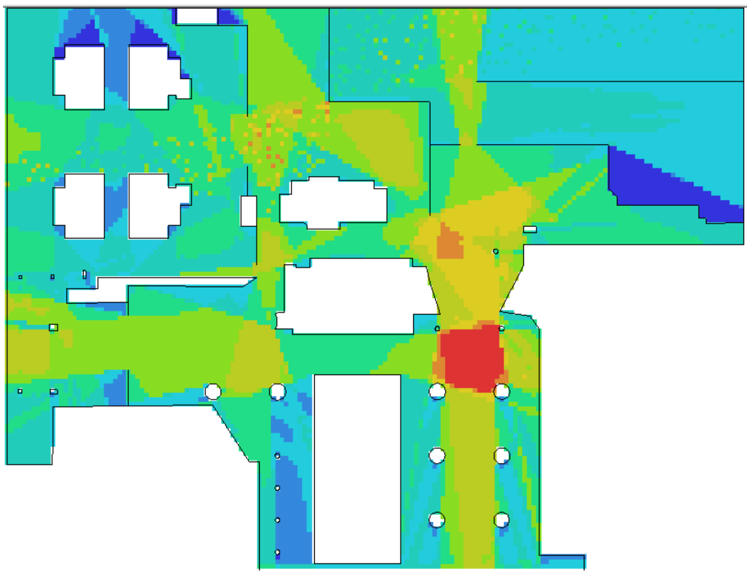

Figure 3: Global integration map (HH) (VGA).

Regarding the locations of the non-aeronautical services, it is observed that the lounge and the retail services are located in very segregated areas. It means that, according to configuration, it is expected to be less probable that these areas will attract people who are randomly moving inside the building and have not planned to visit these places specifically. The opposite result holds for the beverage areas (C1, C2, C3 and C4) the majority of which (C2, C3 and C4) are at rather well visually integrated locations. The visual connectivity of the beverage areas is also better than the overall connectivity of the other activities (retail areas and lounge).

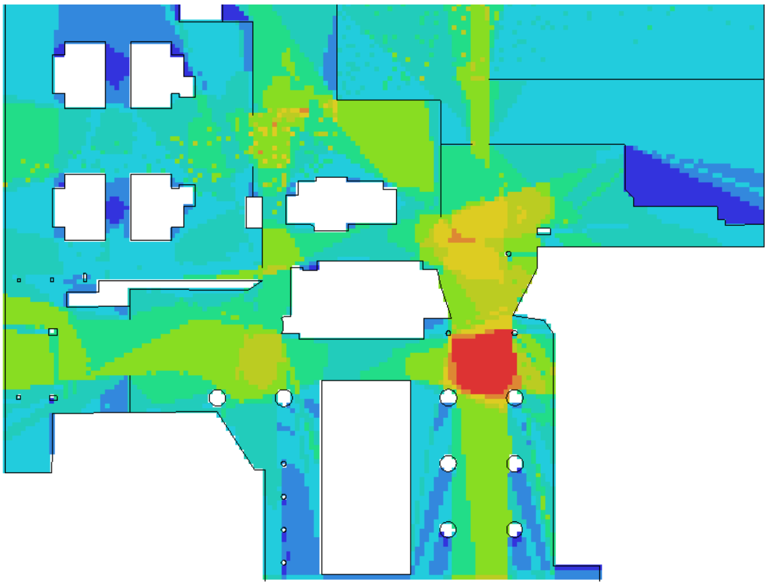

Figure 4: Local integration map (HH3) (VGA).

Figure 5 depicts the relationship among the visual connectivity and visual global integration values (Rn) of the points of the airport plan which gives a sense of the intelligibility of the system according to SS. In this case, the correlation of the two variables is approximately 0,6, meaning that that the plan could be described as slightly intelligible.

The analysis was also developed for the synergy variable, which is expressed as the correlation among global (HH) and local (HHR3) visual integration values (Figure 6). Findings indicate that there are similarities in the configuration of the space in the different airport zones, i.e., the global and the local structure of the spatial layout do not present big differences, probably because of the built space scale.

Modelling passenger choices

The case study airport has four beverage places, three of which are located exclusively inside (C2, C3 and C4 in Figure 1); the last one has an outdoor part too (C1). In order to collect passenger data for the DCM, a revealed preference survey was conducted. The data collection took place during one week of March 2014 from 10am-9pm at the following locations: at the beverage areas, the lounge and the retail, at random points of the building before the security control and inside the security control area before the security scanning corridors.

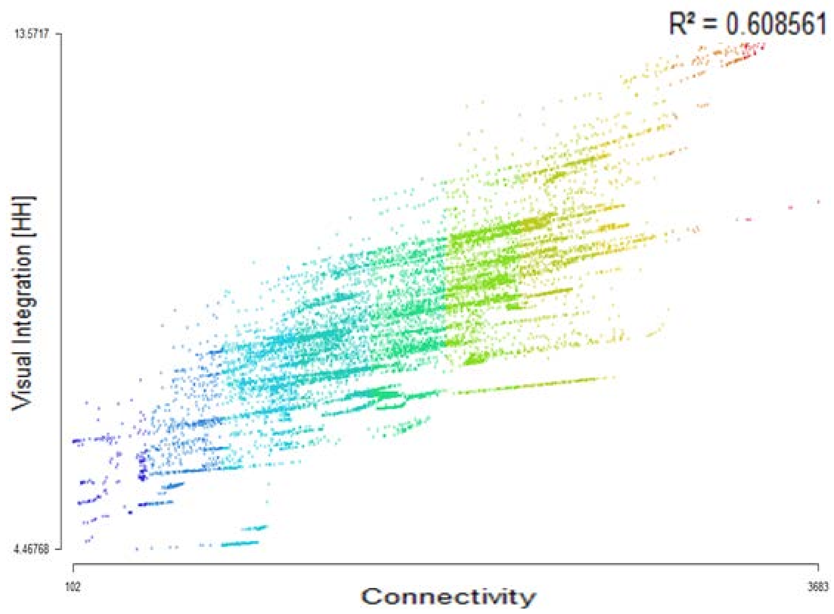

Figure 5: Intelligibility of the investigated plan (global integration and connectivity, VGA).

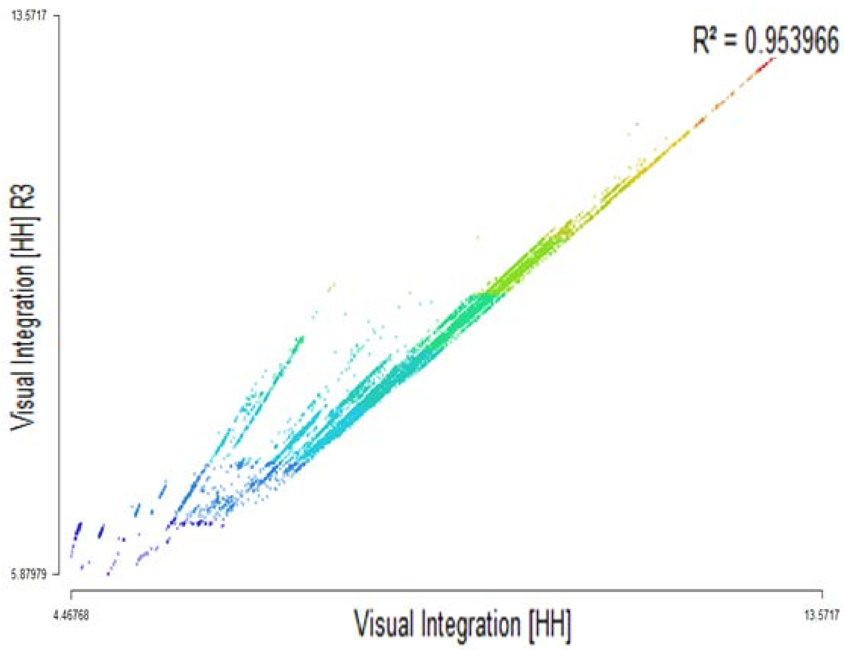

Figure 6: Synergy of the investigated plan (global integration and connectivity, VGA).

Survey description

The data collection was random, with no specific focus on one passenger type, and the composition of the sample was dependent only on the will of the passengers to participate. The survey structure consisted of groups of questions related to time, personal and trip information, activity types and sequence inside the airport, route description and wayfinding issues.

Time-related information included data such as the time that the passenger's flight departs, how much time in advance the passenger: a) arrived at the airport, b) performed (if necessary) the check-in, c) planned to reach or actually reached the security area and when d) she would like to arrive at her gate. Passenger personal information concerned the passenger's age, gender, trip purpose, nationality, city of residence, air travel frequency, stress for flight, stress for time and familiarity with the airport building. In addition, aspects pertinent to the airline, the destination, the number of baggage, the mode of check-in and the mode of arrival at the airport were collected from this section of the survey.

In addition, the passengers were asked to report the number of passengers they travel with, the number of non-travellers with whom they arrived at the airport and, in the case that they arrived by car, whether they used the parking or not. The passengers were also asked to report the activities they performed inside the airport since their arrival until reaching the security control area. Issues relevant to the easiness to move inside the building were also reported. The passengers were asked to recall if they used the flight information board and the signs, if they got lost inside the building and if they used any point as a landmark. Finally, they attributed the building a grade as an evaluation indicator for wayfinding.

Some survey statistics are presented in Table 1. The majority of the passengers were satisfied with their orientation inside the building; they did not have difficulties in wayfinding (~80%) and most of them (~ 80%) used the signage system. Two entrances served the most of the passengers and the majority of the passengers performed the check-in at a counter (57%). The statistics for each beverage area are also presented.

			Total	**C1**	**C2**	**C3**	**C4**
Personal	% male		**63%**	75%	66%	52%	68%
	% Port nationality		**46%**	39%	47%	52%	35%
	% Lisbon_residency		**23%**	22%	22%	28%	15%
Flight	% transfer flight		**22%**	22%	21%	26%	18%
	% Schengen flight		**62%**	69%	57%	61%	68%
	% feel time stress		**13%**	8%	17%	7%	24%
	% feel flight fear		**12%**	11%	12%	12%	12%
Building	% airport familiar	1	**60%**	64%	64%	63%	38%
	% first_time_users	1	**24%**	28%	21%	22%	35%
	confused	1	**14%**	14%	14%	13%	15%
	% lost	1	**3%**	6%	3%	4%	0%
	% signs_users	1	**73%**	72%	74%	70%	82%
	% landmarks	1	**23%**	17%	30%	22%	18%
	Wayfinding	Very easy	**37%**	25%	36%	44%	35%
		Easy	**44%**	56%	45%	37%	44%
		Average	**16%**	17%	17%	15%	15%
		Difficult	**3%**	3%	1%	5%	6%
		Very difficult	**0%**	0%	0%	0%	0%
Trip	% personal	1	**25%**	19%	30%	28%	15%
	% business	2	**35%**	28%	42%	34%	29%
	% tourism	3	**40%**	53%	29%	38%	56%
	% delayed flight	1					
	% baggage	0		44%	30%	34%	24%
		1		39%	48%	46%	47%
		>1		17%	22%	20%	29%
		oversized	**3%**	3%	4%	2%	3%
	travel alone		**51%**	56%	61%	48%	29%
	travel with children		**5%**	0%	4%	7%	6%
	group size	avg	**1**	1	1	1	1
	group size	std	**3**	1	4	2	1
	% online_CheckIn	1	**24%**	31%	31%	16%	21%

	% counter_CheckIn	2	**57%**	44%	52%	65%	62%
	% machine_CheckIn	3	**5%**	8%	4%	4%	9%
	% transfer_CheckIn	4	**14%**	17%	13%	16%	12%
Arrival	arrive alone		**68%**	72%	66%	59%	76%
	% entrance 1	1	**35%**	58%	31%	30%	32%
	% entrance 2	2	**10%**	6%	14%	5%	18%
	% entrance 3	3	**16%**	8%	17%	21%	12%
	% entrance 4	4	**21%**	19%	30%	16%	15%
	% entrance 5	5	**3%**	3%	3%	6%	0%
	% entrance 6	6	**2%**	0%	0%	5%	3%
	% entrance 7	7	**0%**	0%	0%	0%	0%
	% entrance 8	8	**11%**	3%	5%	17%	21%
Activities	Planned before?		**45%**	53%	53%	39%	32%
	Café before check-in		**23%**	25%	31%	21%	6%
	Café after check-in		**56%**	42%	53%	55%	79%
	Café first activity			92%	77%	83%	97%
TIME	Avg time spent at café (min)		**31**	30	32	34	25
	Std spent at café (min)		**26**	39	25	24	18

Table 1: Survey statistics

Discrete choice model of passenger beverage choice

Next, the approach to link SS and passenger behavior through the DCM is presented. Several types of variables were considered to affect passenger propensity to choose an alternative. In terms of SS two indicators were tested: visual connectivity and visual global integration (HH).

For computational reasons, these attributes of the alternatives were evaluated in interaction with passenger characteristics. Visibility was explored in a binary form (0 or 1). The specification of our final model is presented in Table 2. Hereafter, we present the final model that was formed and was found to represent better the passenger choices through the log-likelihood test. All the presented variables were statistically significant and the expected signs were found (Table 3).

Parameter name	**C1**	**C2**	**C3**	**C4**
ASC_C1	1	-	-	-
ASC_C2	-	1	-	-
ASC_C4	-	-	-	1
βvis_CI	-	vis_CI_2	-	vis_CI_4
βcon_CI	connectivity_C1 * cafeBeforeCheckIn	connectivity_C2 * cafeBeforeCheckIn	connectivity_C3 * cafeBeforeCheckIn	connectivity_C4 * cafeBeforeCheckIn
βvis_entrance	visibility CI_1 from entrance	visibility CI_2 from entrance	visibility CI_3 from entrance	visibility CI_4 from entrance
βfamililiar	-	-	-	familiar
βint_onlyBev	integration _C1 * onlyBeverage	integration _C2 * onlyBeverage	integration _C3 * onlyBeverage	integration _C4 * onlyBeverage
βtimeSpent	-	-	-	spent time
βtravelAlone	-	travel alone	-	-
βinternational	international	-	-	-
βonline	-	online	-	-
βparking	-	parking	-	-

Table 2: Model specification

The expected outcomes were given by the model for the visibility from entrance and the check-in areas. Visibility of C2 and C4 from the check-in areas were found to have a positive impact on their utility compared to the other two alternatives.

In relation to the spatial characteristics of the alternatives, the results of the model showed that an increase in the visual integration level of the activity location could add value to the passengers who perform only one discretionary activity, in this case, choose to go to a beverage place. This result was expected since visual integration is a global indicator of SS and can be interpreted as the accessibility value of a location.

Parameter name	Parameter description	Parameter Value
ASC_C1		-0,438
ASC_C2		-0,792*
ASC_C4		0,112
βvis_CI	1if the alternative is visible from the check-in area that the passenger used	0,714**
βcon_CI	Connectivity value * the passenger visited the alternative before the check-in (0,1)	-0,897**
βvis_entrance	1if the alternative is visible from the entrance that the passenger used	0,48**
βfamililiar	1 if the passenger is familiar with airport	-1,14***
βint_onlyBev	Integration value * the passenger visited only the beverage area and no other non-aeronautical area (0,1)	0,347**
βtimeSpent	The time that the passenger spent at the alternative	-0,28*
βtravelAlone	1 if the passenger travels alone	0,649**
βinternational	1 if the passenger travels to an international destination	-1,22***
βonline	1 if the passenger conducted the check-in online	0,781**
βparking	1 if the passenger used the parking area	-2,01***

Table 3: Estimation results for the final model

Notes: * Significant at 10%; ** Significant at 5%; *** Significant at 1%; LL= -217.757, ρ^2= 0.115

At a local scale, for the passengers who visit their choice locations before the check-in, connectivity was found to be an important factor that affects positively the passengers' perception for the utility of the alternative. This also coincides with the presumed hypothesis that was made before the modelling process.

The impact of the trip type (international flight) was tested and found to negatively affect the utility of the first place (C1). This result was expected since this alternative is located further away from the security area compared to the other alternatives. Considering the anxiety of the passengers who perform long trips to pass through all the security processes, this result is representative of the reality. Aligned to this result is also the negative sign of the parameter that represents the time that the passengers spend at their chosen location; it was negative for C4 which is located close to the security, showing that the more time the passenger spend at the beverage area, the less likely it is to choose a beverage are which located close to the security area.

The results also indicated that if a passenger travels alone, it would be more likely to choose C2 assuming that the rest of the utilities were the same. As for the feeling of familiarity with the airport configuration, familiar passengers showed a preference for C1, C2 or C3 compared to C4. In addition, the passengers who used the parking were more likely to visit C1, C3 or C4 compared to C2. This is attributed to the fact that C2 is less connected to the exits of the elevators that connect the floor under analysis with the parking area. In the contrary, the passengers who conducted the check-in online showed a preference for this alternative (C2).

Our results indicate that there is an impact of the current spatial layout on the passenger choices over non-aeronautical activities with same services inside the airport building. Hence, SS can contribute to the formation of "organizational rules" inside terminals in such a way that managerial purposes could be served. Further research could use camera data to check the resemblance of the map of visual integration with the actual movement patterns of the passengers or test the appropriateness of non-structural elements such as removable partitions, mezzanines etc.

5. Conclusion

In this paper the spatial layout of Lisbon Portela airport departures floor was analysed and its impact on passenger choices was explored. Based on the findings and discussion, the attempt to include SS indicators in DCM was rewarding since the initial assumption that SS affects passenger choices was proved through the significance of the equivalent variables that were included in the developed model. It was shown that SS can stimulate passenger choices and favour alternatives that are more accessible or well-connected.

Findings have pointed that the configuration-related SS can contribute to the attraction-related DCM. Traditionally transport engineering has assumed distances as the determinant factor in planning. However, it was proved that SS can add value in explaining passenger choices and in the future it can be incorporated in planning concepts that quantify passenger perception and consider passenger perception as the centre of planning indoor pedestrian facilities.

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