Original article

Application of an evaluation tool for mega-hospital site sustainability. Assessment of public private partnership large sized healthcare infrastructures in European context

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Abstract. *Background and aim:* Healthcare facilities are large and complex infrastructures designed to respond to a growing need of sanitary services in specialized environments to serve an increasing population number while containing costs. New financial and design models emerged for large sized Hospital Facilities (Mega-hospitals) but their site sustainability is questioned. *Methods:* The paper focuses on a comparison between European region case studies of Public Private Partnership (PPP) Mega-Hospitals. A total of 21 large sized hospitals in operation after 2010 have been compared with the application of the Assessment Tool for Hospital Site Sustainability (ATHOSS). A specific focus on Turkish Hospitals has been also provided as the PPP model is widely adopted in this country. *Results:* This analysis shows that Turkish cases gets general lower scores than European ones in terms of Construction Density and Community Connectivity (28%;50%), Alternative Transportation (18%; 50%), Site Development (26%; 38%). Connection to Natural World (30%; 52%) and Heat Island Effect (33%; 43%). Only in Development Density criteria (30%; 16%) the score was higher. It also emerged that gross floor area per bed ratio is much larger for Turkish cases ($334 m^2$/bed; $198 m^2$/bed) which can be interpreted as one of the weaknesses related to oversizing such infrastructures. *Conclusions:* The tool application highlighted some point of attention to be considered when designing and planning Mega-hospital facilities and improvement strategies for site sustainability are suggested. (www.actabiomedica.it)

Key words: Site sustainability, healthcare facilities, public private partnership (PPP), hospital evaluation, assessment tool, mega hospital, one health

Introduction

Healthcare services are transforming and developing continuously to address health needs of the population and countries are looking for operative strategies to achieve the aim of Sustainable Development Goal (SDG) n°3 - Ensure healthy lives and promote wellbeing for all at all ages (1). A well-functioning health care system requires a sustainable financing mechanism, a well-trained and adequately paid workforce, reliable information on which to base decisions and policies, and well maintained healthcare infrastructures to host processess and technologies (2). The need of specialized healthcare services, an ageing society and the growing urban population are driving some policy makers to experiment a centralized model of acute care assistance within a network of low and medium care facilities distributed on the territory.

Centralizing high quality services for a huge population area means implementing large-scale facilities to accommodate those transforming needs.

Such facilities also known as Super-Hospitals or Mega-Hospitals are very large, complex and integrated organizations having a bed capacity of minimum 800 up to thousands of beds and multiple operating rooms. These buildings hold multiple purposes such as basic health services, commercial activities, administration, etc. and offer several horizontally and vertically integrated health services including a variety of clinical branches, outpatients and inpatients activities, as well as emergency and variety of diagnostic services (3). Such huge and concentrated development needs large greenfield and is today questioned in terms of site sustainability and land consumption reduction with specific regards also to SDG n°11 and related indicator "Ratio of land consumption rate to population growth rate" (4,5). This model has been adopted in several European countries such as Denmark (6) and United Kingdom (UK) (7) and systematically applied in Turkey since 2017 to an ambitious Mega-Hospital PPP plan of new so called "City-Hospitals" ranging between 1000 to almost 4000 beds capacity (8,9). In this plan such new hospitals had to guarantee highest level of sustainability with specific attention to environmental sustainability certifications (10).

Due to their size, complexity, capital costs allocated for the initial investment and articulated functional mix such facilities usually reach their operation phase thanks to the use of Public Private Partnership (PPP) procedures and financial models (11). PPP is a form of cooperation between public authorities and the private sector that aim to provide effective infrastructure and strategic Public Health services with sustainability targets from economic, social and environmental perspectives (12). Within this framework, objectives for sustainable healthcare infrastructures involve generate less waste, minimize impact on the landscape, and use less energy, water, and natural resources. Site selection, development density, community connectivity, alternative transportation, heat island effect, light pollution reduction and waste management are some of the criteria that are measured under the topic of site sustainability. These are topics that gained momentum after the 70s climate crisis and they are getting more relevant with exponential urbanization and technological advancements. Today such issues are incorporated in a renovated vision of sustainability as key strategy for healthier environments as embedded in the holistic vision of the One Health approach (13,14). Assessment of both qualitative and quantitative data for sustainability of healthcare structures is an essential way to understand and develop the facilities and the projects (15,16). International protocols such as LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method) can be also adapted on healthcare building sustainability (17–19). Nevertheless, the peculiarities of PPP Mega-Healthcare Facilities are challenging to highlight only with those standard tools. Therefore, evaluation framework specifically designed for such infrastructures are needed to be updated, revised and tested accordingly.

Research gap and objective

Healthcare facilities are large and complex infrastructures designed to respond to a growing need of sanitary services in specialized environments to serve an increasing population number with lowering costs. New financial and design models emerged for PPP large sized Hospital facilities (Mega-Hospitals) but especially due to their size, their site sustainability is questioned in relationship to need of soil consumption reduction and relationship with the urban context, services and accessibility. The study aim is to use a multiple criteria tool developed at Politecnico di Milano, Italy on a sample of PPP Mega-Hospital structures in the European region (20,21). In particular the study compares the Turkish systematic use of this model for the recent hospital developments with other European countries experiences.

Materials and methods

Data collection

The focus of this research is PPP model mega hospital projects' site sustainability analysis and assessment. The methodological objective is to apply a preliminary assessment element to test an instrument and see the results. In this regard, seven countries stand out as utilizing PPP model abundantly for infrastructure projects and have substantial experience in this field: Denmark, United Kingdom (UK), Italy, Germany, Spain, Sweden and Turkey. A total of 45 hospital projects have been collected from these countries and screened through a process of inclusion and exclusion criteria for the evaluation. In particular the criteria are related to:

- Infrastructures financed by Public-Private Participation model: since this research puts the PPP model in the center of the study due to its increasing use in the last decades for mega-hospital projects, it is essential to choose only the hospitals that are financed, built and being operated with this model to standardize the sample set. All the hospitals selected are financed by PPP models.
- Recent construction: the hospitals considered for the further analysis are operational from 2010 or after therefore a 10-year limitation for the operation have been considered sice it is the average time for construction healthcare facilities in European context. This point is important when considering the technological improvements and healthcare standards needs and requirements that change quickly over time.
- Adequate size: hospitals with 800 beds or more have been included in order to have comparable sample and large-scale facilities; case studies that have bed capacity under 800 have been excluded from the selection.
- Comparable geographical context: only hospitals in various European region countries have been included in the study to compare the hospitals within the same continent whose construction and financial model might refer to similar regulatory context.
- After applying the aforementioned criteria, a total of 21 hospital case studies have been included in the final analysis, as reported in the flowchart in Figure 1.

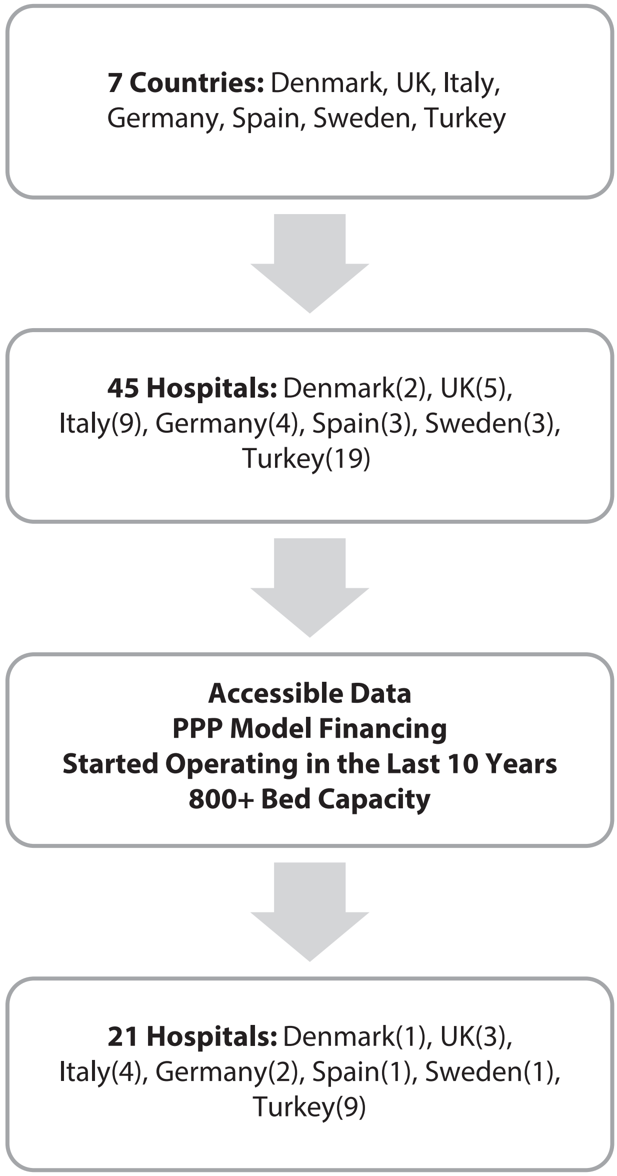

Figure 1. Sample Hospital Shortlisting Scheme.

Data collection has been conducted between 1st August 2020 and 31st July 2021 with an extensive investigation that involved both primary and secondary data with the following tools:

- Satellite images for before and after construction site situation, numeric values and public transportation patterns have been extracted from Google Earth Pro

- Written information about technical and operational aspects of hospital facilities, drawings, photos and visual documentations have been found on web pages related to hospital projects through official hospital web page, architectural office/construction company webpage and specialized online websites (i.e. ArchDaily)
- Qualitative and quantitative information related to each different hospital project have been collected from scientific and technical publications.
- Detailed information and confidential documents (i.e. technical drawings, plans, sections, economic data) have been collected through email, phone or face-to-face semi-structured interviews with the construction company, hospital planner or government agency involved in each project.

This study focuses on qualitative and quantitative comparison and assessment of 12 European and 9 Turkish hospitals selected on 6 macro criteria and 17 micro criteria based on the ATHOSS tool, a site sustainability assessment tool developed by ABC Department of Politecnico di Milano, Italy (20,21). The main goal of ATHOSS is to measure site sustainability with today's hospital performance levels and provide a guide for the decision-making process. It claims to be used in site selection, site planning and site sustainability measurement and improvement process; being suitable for both already built hospitals and hospital projects in design phase. ATHOSS also points out being free of charge and easy-to-use, which makes the assessment possible even for the ones who are not complete experts in the field of site sustainability. It is an assessment tool very specific for hospital site sustainability that collect indicators from other existing tools on environmental sustainability in general. The 6 macro criteria to be focused on are Development Density (Macro Criteria 1), Construction Density and Community Connectivity (Macro Criteria 2), Alternative Transportation (Macro Criteria 3), Site Development (Macro Criteria 4), Connection to Natural World (Macro Criteria 5) and Heat Island Effect (Macro Criteria 6) as reported in Table 1.

The aim is to analyze maximum number of sample hospitals for the richness and the accuracy of the research and for the results obtained to be reliable.

Data analysis

Data analysis consisted in the comparison of different case studies starting from general data and then the specific application of the tool to see how the hospitals performed. Following the application of ATHOSS tool to every hospital by using the data obtained, tables are prepared to compare both macro and micro criteria of the hospitals, as well as the European and Turkish hospital scores. In particular descriptive statistical analysis have been performed in a Microsoft Excel spreadsheet in order to highlight differences between European and Turkish sample in terms of average, median and mode to enable related considerations. The performances and critical ratios of each sample hospital are presented along with a set of design suggestions and strategies to propose an optimal scenario of a PPP Mega hospital model. The ATHOSS criteria are to be reversely calculated and an optimum numeric value or percentage defines the key elements of the guidelines. Should these guidelines be followed to the extent possible, the design would be naturally complied with site sustainability criteria of ATHOSS. This approach can be adopted both for a new mega hospital to be designed or to revise an already built project.

Results

Based on the findings of the case studies analysis conducted on 12 European and 9 Turkish PPP model Mega-hospitals, the following major differences are observed. As shown in Table 2, the overall rating of European ATHOSS reached an average of 11.4 with hospitals positioning in a range between 9 to 17 out of 26 points with median of 10 and mode of 9. On the contrary the overall rating of Turkish hospitals has 7 points as average and median while mode of 6; in fact they scored between a range of 4 to 10 out of 26 total points achievable (Figure 2 and 3). The European Hospitals' Macro Criteria averages are mostly higher than the Turkish Hospitals' despite the fact that the Turkish Hospitals are relatively newer structures than the European ones, with the exception of Macro Criteria 1 which is the Development Density.

Table 1. Summary of the criteria and indicator for ATHOSS tool.

N°	Criteria	Indicators	Max score
C1	Development Density	Total Project Area [sqm.] Site Area [sqm.] Ratio Total Project Area / Site Area [-]	2
C2	Construction Density and Community Connectivity	Total Project Area [sqm.] Construction Site Area [sqm.] Ratio Construction site Area / Total project Area [-] Number of Basic Functions in a radius of 800mt. [n]	2
C3	Alternative Transportation	Rail station proximity [mt.] Bus station proximity [mt.] Parking capacity total/with/without cover [n] Ratio Total Project Area/ Total Car Parking Capacity [-]	5
C4	Site Development	Building footprint [sqm.] Vegetated Roof Area [sqm.] Vegetated Roof Area/Building Footprint [%] Total Green Space Area [sqm.] Total Green Space Area/Total Site Area [%] Expansion Space: Site Area minus Building Footprint [sqm.] Expansion Space/Site Area [%]	5
C5	Connection to the Natural World	Net Usable Program Area [sqm.] Courtyards Area [sqm.] Net Usable Program Area / Courtyards Area [%] Outdoor Area [sqm.] Ratio Outdoor Area / Net Usable Program Area [%] Existing Water Element [yes/no] Distance from Existing Water Element [mt.]	6
C6	Heat Island Effect	Solar Panel Canopy [yes/no] Tree Canopy [yes/no] Orientation and Shading Strategy [yes/no] Covered Car Parking Capacity under tree/solar canopy/ underground [n] Covered Car Parking/Total Car Parking [%]	6
		Total score	**26**
	Critical ratios	Contract Cost [million €] Gross Floor Area [sqm.] Bed Capacity [n] R1 Ratio 1: Cost/ Gross Floor Area [million €/sqm.] R2 Ratio 2: Cost/Bed Capacity [million €] R3 Ratio 3 - Gross Floor Area/Bed Capacity [-]	-

Critical ratios

Hospital construction costs represent a critical issue, in particular for such large sized facilities both for the capital expenses considered but especially for the impact that design solutions have on operative costs (22,23).

Therefore, Cost per area, cost per bed and area per bed are chosen as the critical ratios to be compared (Table 3). As far as these ratios are concerned, there is a significant difference between Turkish and European hospitals. Although the cost per area and cost per bed of Turkish hospitals are relatively lower than European hospitals whereas the area per bed of Turkish hospitals are substantially higher than the European hospitals. In general, European hospital samples are compact with higher costs whereas the Turkish ones have larger spaces to lower costs.

Table 2. Application of ATHOSS on the 21 case studies.

		Macro Criteria 1 - Development Density (max: 2 points)	Macro Criteria 2 - Construction Density and Community Connectivity (max: 2 points)	Macro Criteria 3 - Alternative Transportation (max: 5 points)	Macro Criteria 4 - Site Development (max: 5 points)	Macro Criteria 5 - Connection to Natural World (max: 6 points)	Macro Criteria 6 - Heat Island Effect (max: 6 points)	Total (max: 26 points)
Hospital 1 (EU)	*Aarhus University Hospital*	2	2	3	3	5	2	**17**
Hospital 2 (EU)	*Royal London Hospital*	0	1	5	0	1	2	**9**
Hospital 3 (EU)	*St. Bartholomew's Hospital*	0	1	5	0	0	2	**8**
Hospital 4 (EU)	*San Stefano Hospital, Prato*	0	2	2	3	3	4	**14**
Hospital 5 (EU)	*San Jacopo Hospital, Pistoia*	1	0	2	2	3	1	**9**
Hospital 6 (EU)	*San Luca Hospital, Lucca*	0	1	2	2	3	1	**9**
Hospital 7 (EU)	*Apuane Hospital, Massa*	0	1	1	2	4	1	**9**
Hospital 8 (EU)	*Southmead Hospital*	0	0	2	3	6	4	**15**
Hospital 9 (EU)	*Schleswig Holstein University Hospital, Kiel*	0	1	1	2	2	4	**10**
Hospital 10 (EU)	*Schleswig Holstein University Hospital, Lubeck*	0	1	2	0	3	4	**10**
Hospital 11 (EU)	*Alvaro Cunqueiro Hospital*	1	1	3	3	5	3	**16**
Hospital 12 (EU)	*New Karolinska University Hospital*	0	1	2	2	2	4	**11**
	Average	**0.3**	**1.0**	**2.5**	**1.9**	**3.1**	**2.6**	**11.4**
	Median	**0**	**1**	**2**	**2**	**3**	**2.5**	**10**
	Mode	**0**	**1**	**2**	**2**	**3**	**4**	**9**
Hospital 13 (Turkey)	*Mersin City Hospital*	0	0	1	0	1	2	**4**
Hospital 14 (Turkey)	*Adana City Hospital*	0	1	1	3	3	2	**10**
Hospital 15 (Turkey)	*Elazig Fethi Sekin City Hospital*	0	1	1	1	2	2	**7**
Hospital 16 (Turkey)	*Eskisehir City Hospital*	0	0	0	2	2	2	**6**
Hospital 17 (Turkey)	*Ankara Bilkent City Hospital*	0	1	1	1	1	2	**6**
Hospital 18 (Turkey)	*Bursa City Hospital*	2	0	1	2	2	2	**9**
Hospital 19 (Turkey)	*Kayseri City Hospital*	1	1	1	0	1	2	**6**
Hospital 20 (Turkey)	*Istanbul Basaksehir City Hospital*	0	0	1	2	2	2	**7**
Hospital 21 (Turkey)	*Konya Karatay City Hospital*	2	0	1	1	2	2	**8**
	Average	**0.6**	**0.4**	**0.9**	**1.3**	**1.8**	**2.0**	**7.0**
	Median	**0**	**0**	**1**	**1**	**2**	**2**	**7**
	Mode	**0**	**0**	**1**	**1**	**2**	**2**	**6**

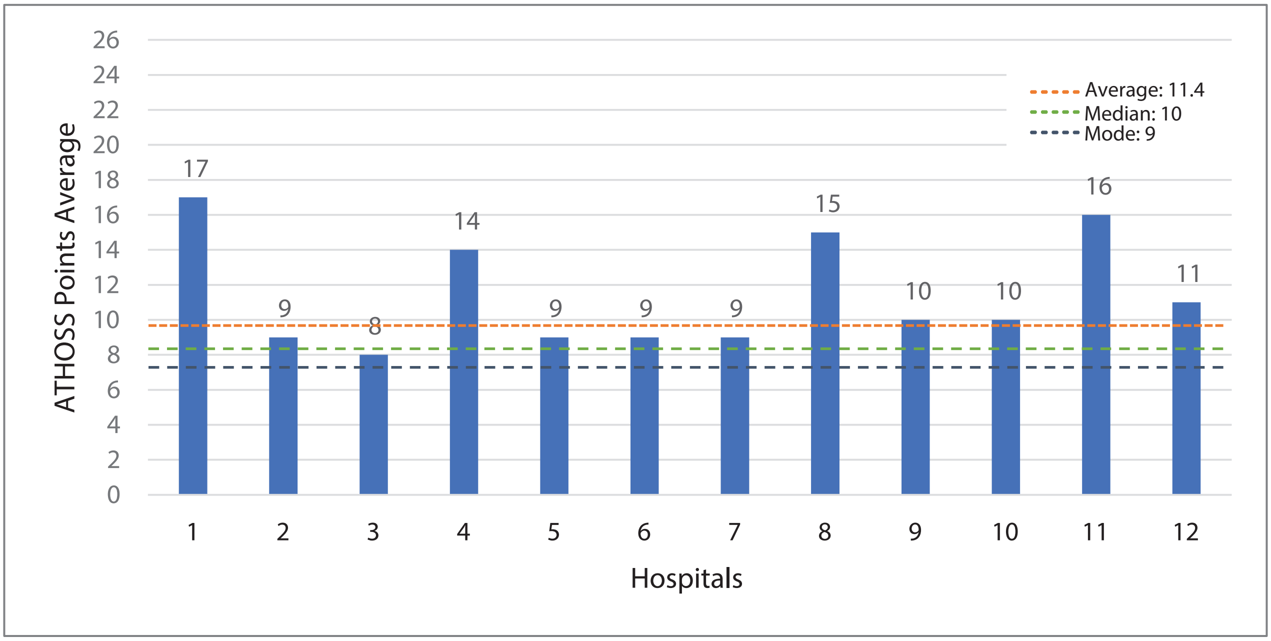

Figure 2. ATHOSS Criteria Points for European Hospitals.

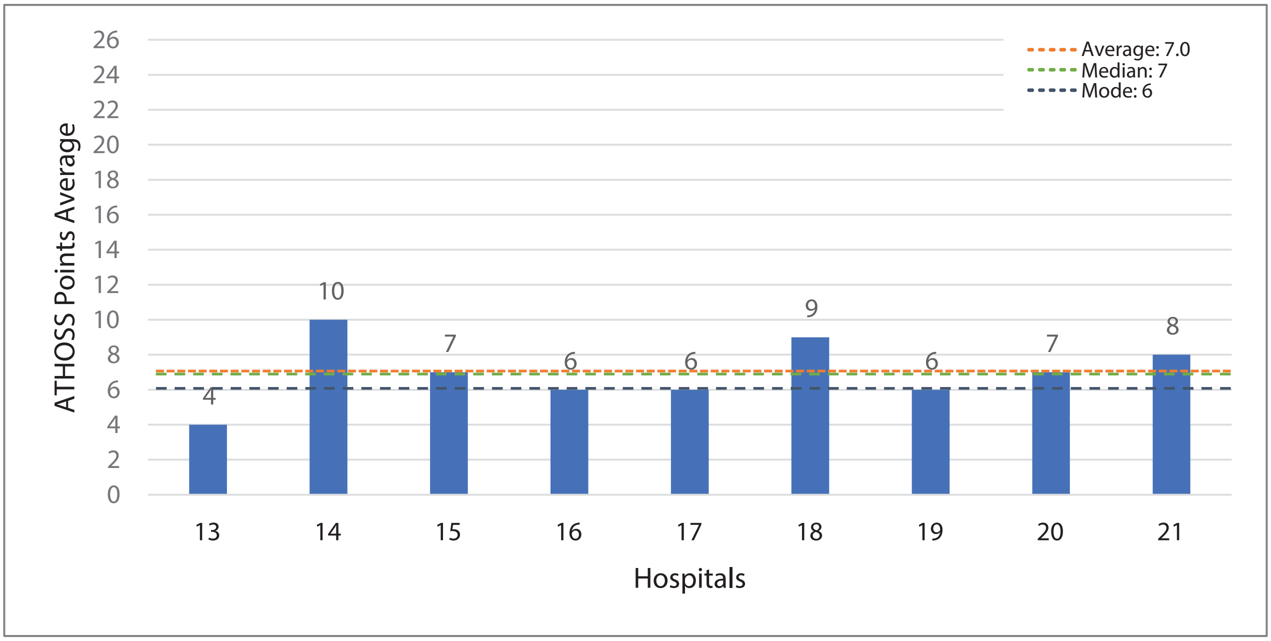

Figure 3. ATHOSS Criteria Points for Turkish Hospitals.

Development density

The first Criteria (C 1 - Development Density) is based on a ratio between Site Area and Gross Floor Area of the healthcare projects which needs to be lower than 70% according to different options: if the project is located in a dense urban area surrounded by city blocks or buildings, it is classified as Option 1; if the project is on a land adjacent to an underdeveloped or green land at least on one side, it is classified as Option 2; if the

Table 3. Hospital Critical Ratios

	Hospitals	CC	GFA	BC	R1	R2	R3
1	Aarhus University Hospital	855	375.000	1.150	2.280	743.478	326
2	Royal London Hospital	1.600	270.000	1.248	5.926	1.282.051	216
3	St. Bartholomew's Hospital						
4	San Stefano Hospital, Prato	419	351.050	1.710	1.194	245.029	205
5	San Jacopo Hospital, Pistoia						
6	San Luca Hospital, Lucca						
7	Apuane Hospital, Massa						
8	Southmead Hospital	469	11.000	832	4.114	563.702	137
9	Schleswig Holstein University Hospital, Kiel	520	67.300	2.400	7.727	216.667	28
10	Schleswig Holstein University Hospital, Lubeck						
11	Alvaro Cunqueiro Hospital	484	280.000	1.465	1.729	330.375	191
12	New Karolinska University Hospital	1.420	320.000	1.340	4.438	1.059.701	239
European Average of Ratios					3.250	634.429	198
13	Mersin City Hospital	610	369.590	1.294	1.650	471.406	286
14	Adana City Hospital	433	550.000	1.550	787	279.355	355
15	Elazig Fethi Sekin City Hospital	288	360.000	1.038	800	277.457	347
16	Eskisehir City Hospital	344	341.287	1.081	1.008	318.224	316
17	Ankara Bilkent City Hospital	1.800	1.312.000	3.711	1.372	485.044	354
18	Bursa City Hospital	330	465.000	1.355	710	243.542	343
19	Kayseri City Hospital	145	466.379	1.607	311	90.230	290
20	Istanbul Basaksehir City Hospital	1.100	1.019.000	2.682	1.079	410.142	380
21	Konya Karatay City Hospital	350	421.566	1.250	830	280.000	337
Turkish Average of Ratios					942	317.266	334

Legend: **CC**: Contract Cost (million €); **GFA**: Gross Floor Area (sqm.); **BC**: Bed Capacity; **R1**: Ratio 1 - Cost/Gross Floor Area (million €/sqm.); **R2**: Ratio 2 - Cost/Bed Capacity (million €); **R3**: Ratio 3 - Gross Floor Area/Bed Capacity (-).

project is surrounded by underdeveloped or green lands on all sides, it is classified as Option 3. Later, the Site Area is divided to Gross Floor Area and the points are given according to the intervals that are corresponding to each option. Overall European hospital average was 0.33 (16%) while Turkish scored higher resulting in 0.6 (30%). Both samples had median and mode equal to 0 (Figure 4 and 5).

Construction density and community connectivity

The second Criteria (C 2 – Construction Density and Community Connectivity) is based on two numeric values one being the ratio of Construction Site Area over Gross Floor Area and the second one being the number of basic functions in 800-meter radius. From the first part of this criteria, the hospitals get 1 point if the ratio is bigger than 1.18; and they cannot get any points if the ratio is smaller than this value. This is a parameter to control the density of the overall constructed area inside the site boundaries. There are only 2 European hospitals that got points from this section while all the other 19 hospitals could not get any points due to their high density of construction. All of the Turkish hospitals got 0 point from construction density which means the gross floor area of these hospitals are larger than what is expected from this tool. The ratio of gross floor area per bed is higher

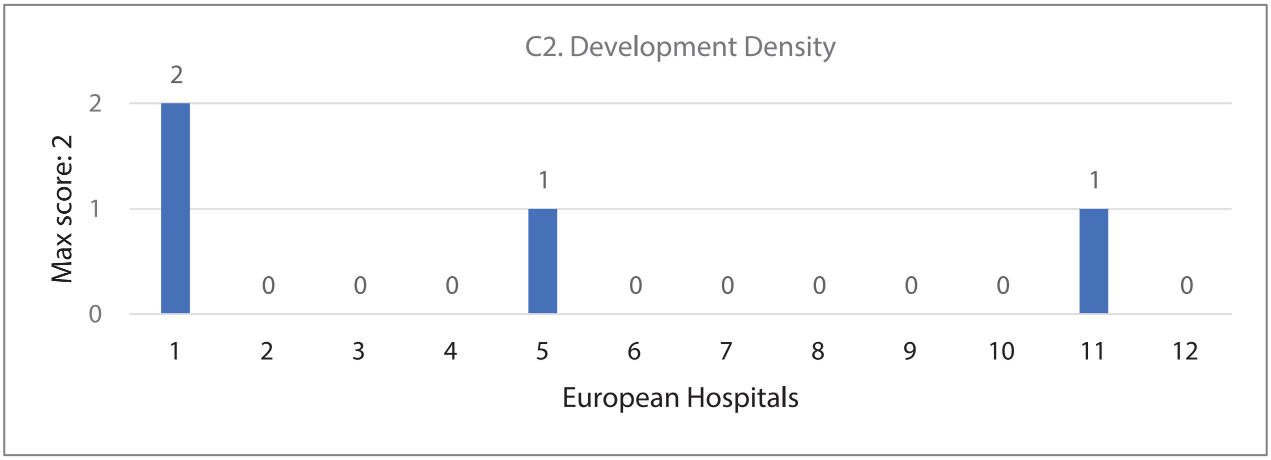

Figure 4. ATHOSS Criteria 1 scores for European Hospitals.

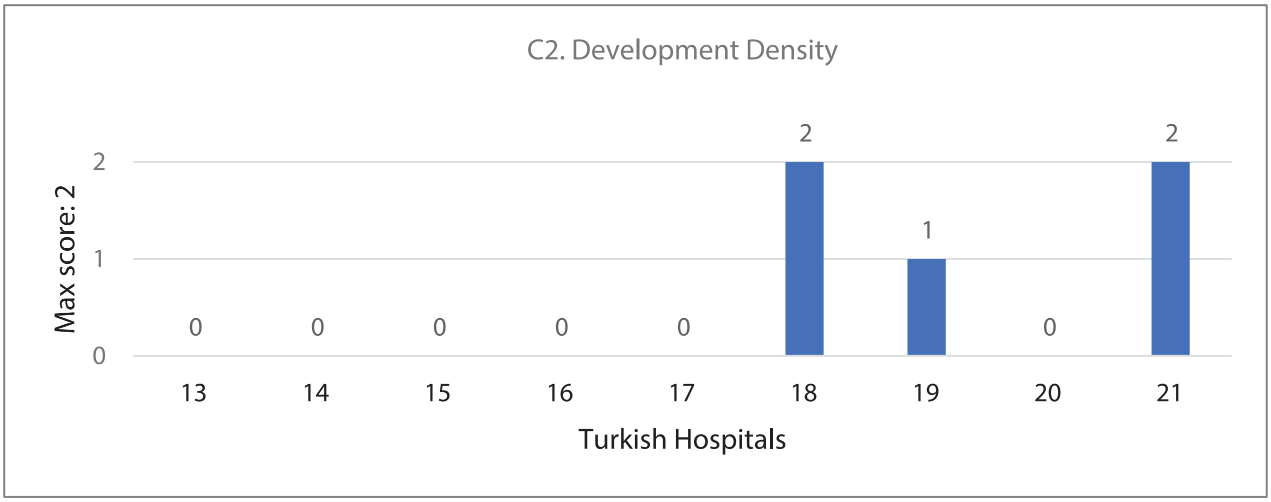

Figure 5. ATHOSS Criteria 1 scores for Turkish Hospitals.

for all these Turkish hospitals compared to European ones. This is another indication supporting the accuracy of this fact. The second part of this criteria is directly related to the presence of basic functions in close proximity of healthcare facilities. This section requires a minimum of 10 basic functions in 800-meter radius when the hospital is located in the center of the imaginary circle, to get 1 point. These functions can be market, restaurant, bank, pharmacy, school, post office, and many other daily facilities. 10 European hospitals got full points from this requirement while only 4 Turkish hospitals achieved that. Overall European average was 1 (50%) while Turkish average was 0.57 (28%). European hospital had mode and median of 1 while Turkish sample resulted in 0 as mode and median value (Figure 6 and 7).

Alternative transportation

The third Criteria (C 3 - Alternative Transportation) is based on three ways of transportation such as the rail system, bus and car. The first two; rail system and bus are evaluated depending on the distance of the closest stops from the hospital buildings entrances and the third one, car park is evaluated by the ratio of total area over car park capacity. For the first two parts, the

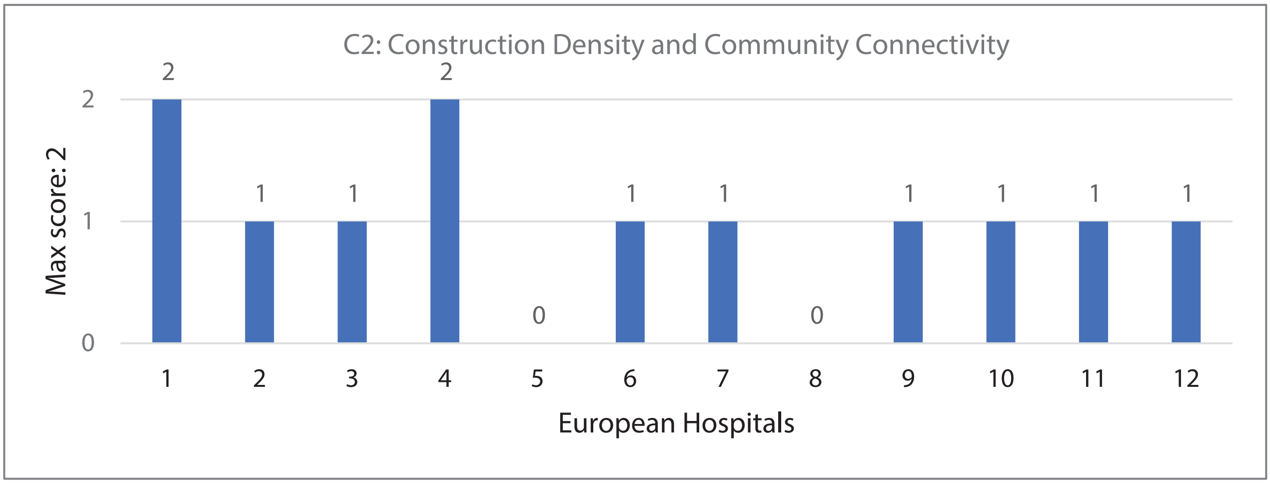

Figure 6. ATHOSS Criteria 2 score for European Hospitals.

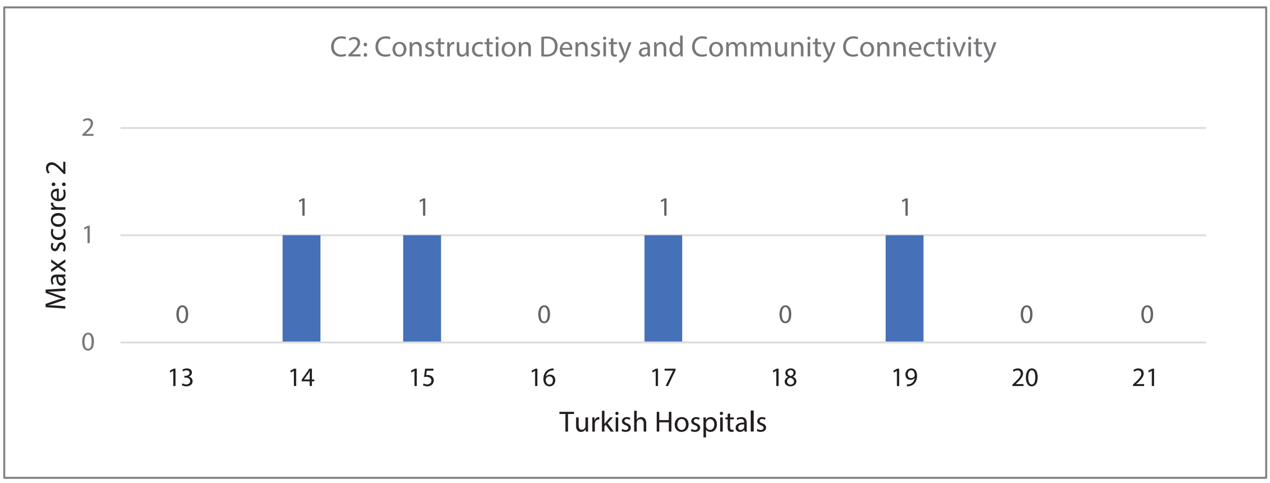

Figure 7. ATHOSS Criteria 2 score for Turkish Hospitals.

project gains more points as the distance of the hospitals from the stop decreases, and the point interval is 0-2 for both sections. Furthermore, for the third part the hospital gains 1 point if the ratio is higher than 133, and cannot get any points if the ratio is lower. In general, all of the European hospitals got 1-2 points for being close to bus stops and they lost points either for not being close to rail system or not having a satisfactory ratio between car parking space and the gross floor area. In this criterion the European average is 2.5 (50% of fulfillment) with median and mode equal to 2 while the Turkish average is 0.9 as average (18% of fulfillment) with 1 as mode and median. Overall it is expected that the total number of car park capacity should be less than 0.75% of Gross Floor Area. There should be a train station or railroad system in less than 411 meters to the project. and there should be a bus stop in less than 69 meters to the project; for modifications during Operational Stage, the interventions are of low complexity and shuttle stops or existing transportation patterns can be integrated in the project (Figure 8 and 9).

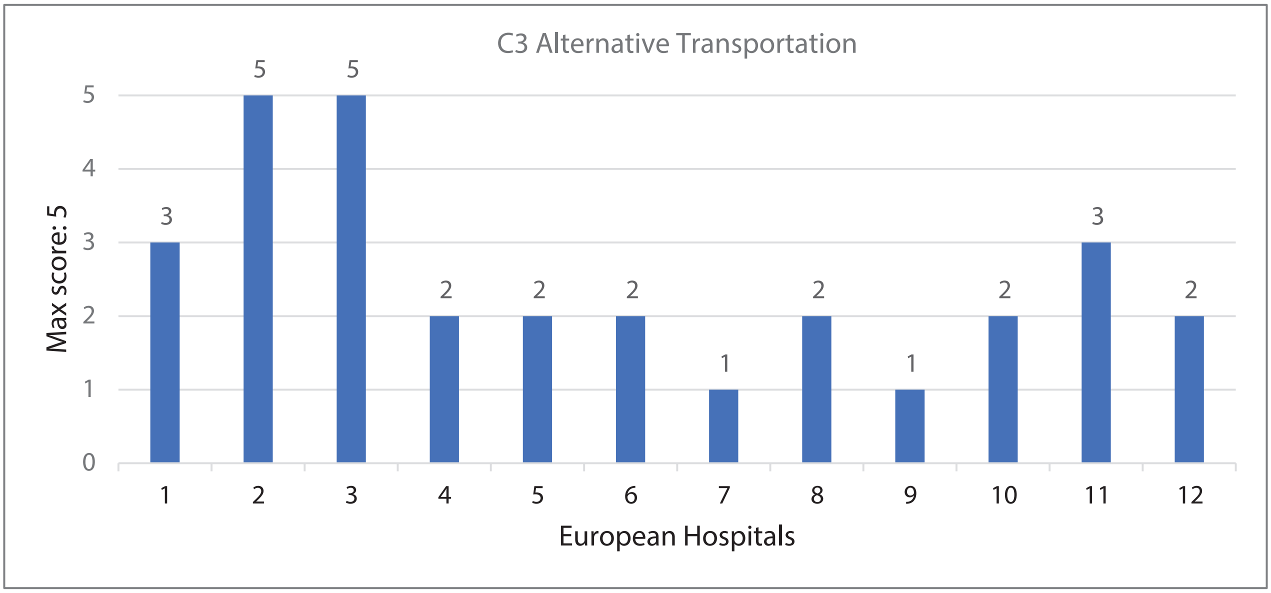

Figure 8. ATHOSS Macro Criteria 3 Points for European Hospitals.

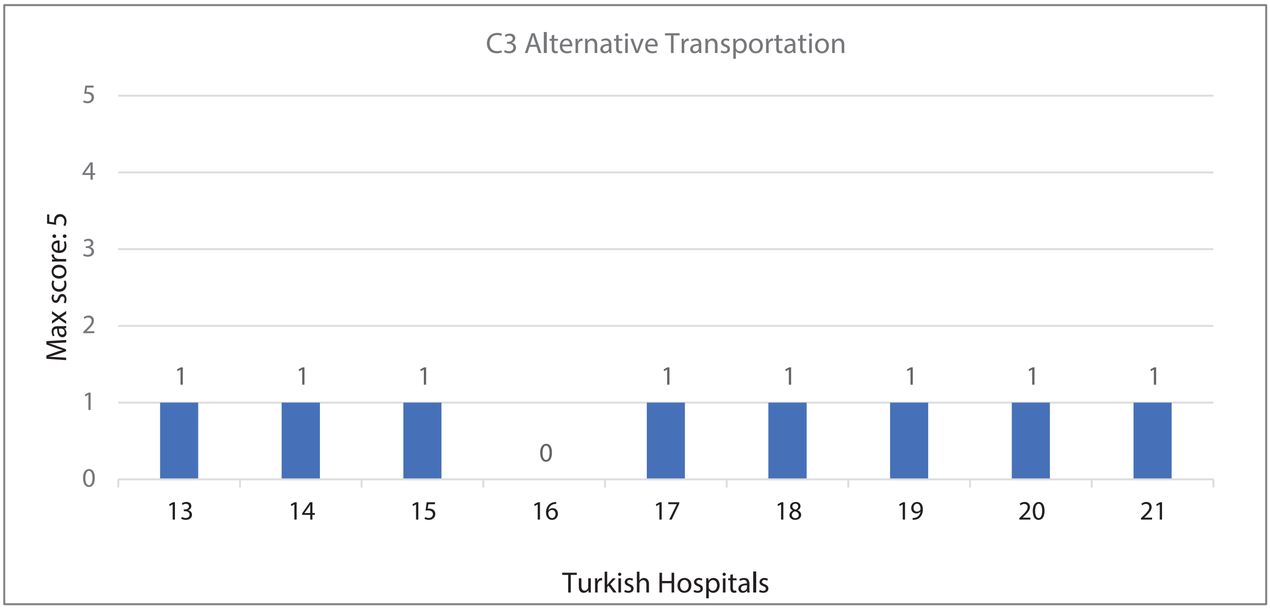

Figure 9. ATHOSS Macro Criteria 3 Points for Turkish Hospitals.

Site development

The fourth Criteria (C 4 - Site Development) is based on the usage of green roofs, open green spaces and ratio of outdoor spaces. Hospitals got 1 point if the vegetated roof is more than 11.8% of the building footprint; 1 or 2 points if the total green area is more than 21% of the total site or 37% of the total site, respectively; and additionaly points if the outdoor area is more than 70% of the site area. This criteria gives a maximum of 5 points, however none of the hospitals could get full score. There is not a particularly successful sample for this criteria; the hospitals are having points between 0-3 both in Europe and Turkey, with the averages of 1.9 (38%) and 1.3 (26%) respectively, mode and median of 2 and 1 respectively. However, with an exception of one hospital, Adana City Hospital, all the Turkish hospitals failed in the micro criteria of green space ratio over total site area. Even though 7 of them contain green roofs, it is not sufficient to reach the minimum required total green space. On the other hand, for Europe there are three hospitals that got 0 point in total for the macro criteria. Two of them are the hospitals in London (Royal London Hospital and St. Bartholomew's Hospital). They do not have green roofs and the external green space and outdoor area in the dense urban block are not sufficient. The third one is the Schleswig Holstein University Hospital in Lubeck, Germany has a similar situation. It is an extension building of an already existing healthcare campus and is built on a small land. The overall land contains green spaces and outdoor area but, the PPP extension project does not cover those aspects and the calculation of the ATHOSS is made considering only the extension project (Figure 10 and 11).

Connection to natural world

The fifth Criteria (C 5 - Connection to Natural World) is based on three different aspects, for a total of 6 points. The healing effect of natural elements for hospital environments is a known fact and this criteria ensures

Figure 10. ATHOSS Criteria 4 Points for European Hospitals.

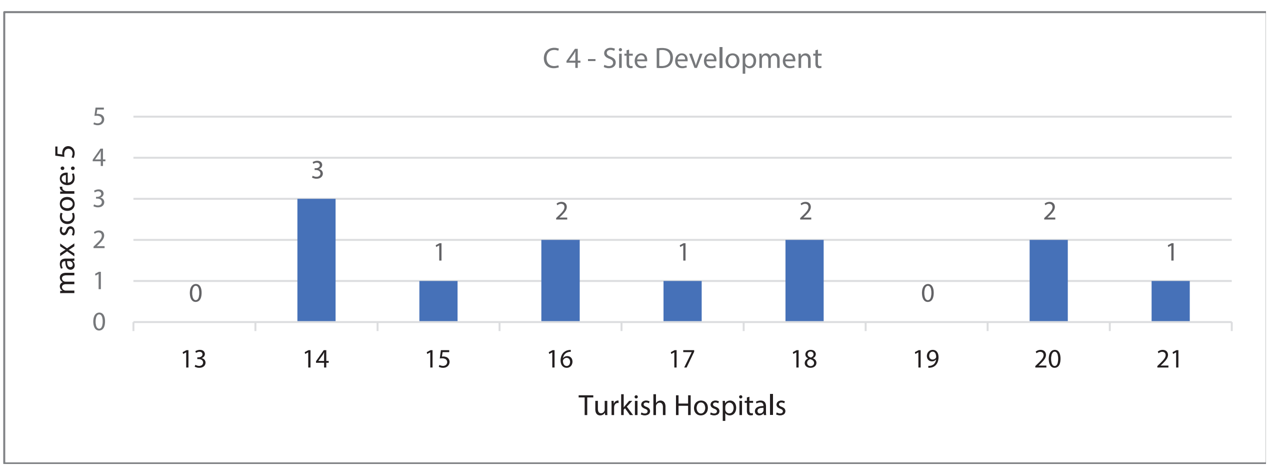

Figure 11. ATHOSS Criteria 4 Points for Turkish Hospitals.

that these conditions are satisfied. The first part is the ratio of courtyards over net usable area. If the ratio is between 2-7%, the hospital gets 1 point and if it is larger than 7%, the hospital gets 2 points. The second part is the outdoor space ratio over net usable area. If the ratio is between 6-29%, the hospital gets 1 point and if it is larger than 30%, the hospital gets 2 points. The last part is depending on the presence of any water element in the hospital site. If there is any, the hospital gets 1 point, and if it is less than 135 meter away, the hospital gets another 1 point. The European average is 3.1 (52%) with mode and median of 3 while the Turkish average is 1.8 (30%) with mode and median of 2. All of the Turkish hospitals lost points from the first and the third part. Even though some hospitals have courtyards, the ratio is not sufficient and all of them got 0 point from the first micro criteria. Moreover, all of the hospitals got 0 point from the third micro criteria except Adana City Hospital that got 1 point for having a water element in the site. In the second part, most of the hospitals either got 1 or 2 points. On the other hand, there is 1 hospital that got full points and two hospitals that got 5 points in Europe that are Southmead Hospital with 6 points (100%); and Aarhus University Hospital and Alvaro Cunqueiro Hospital with 5 points(83%). All of these hospitals have very generous courtyards and water elements in close proximity. The third micro criteria, water element presence, is a common weakness for almost all of the European hospitals. 8 out of 12 hospitals got 0 points (0%) from this criteria (Figure 12 and 13).

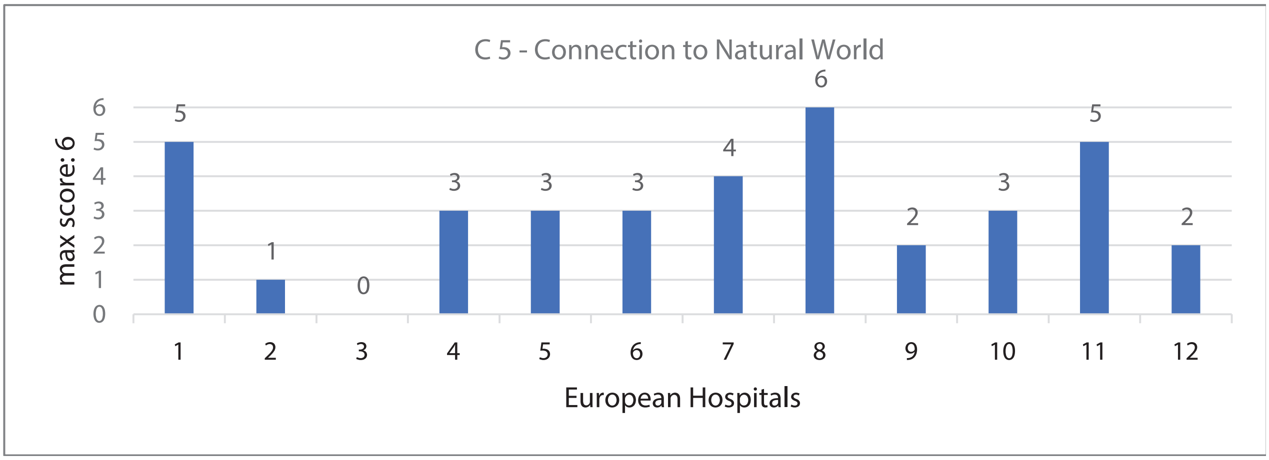

Figure 12. ATHOSS Criteria 5 scores for European Hospitals.

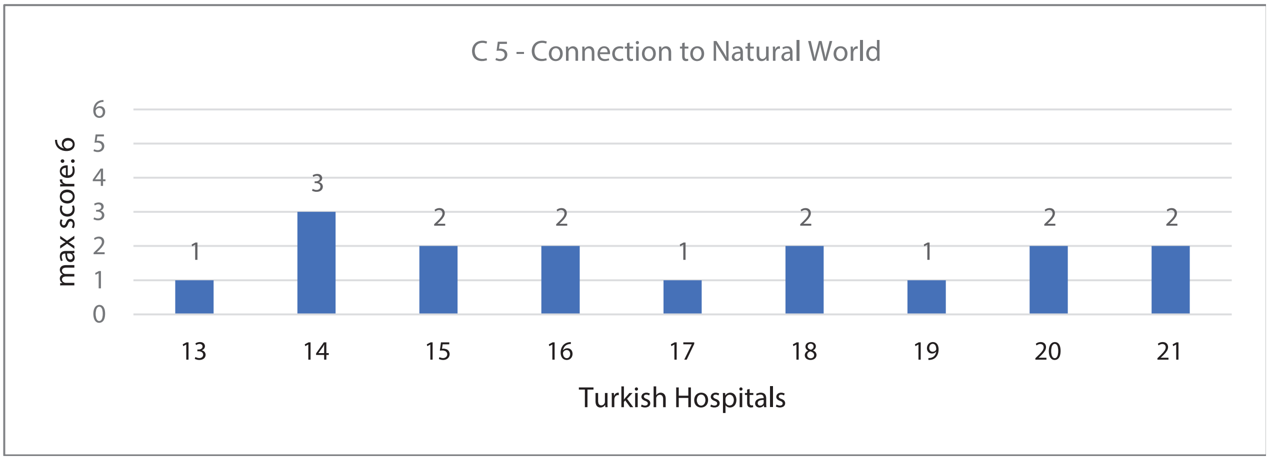

Figure 13. ATHOSS Criteria 5 scores for Turkish Hospitals.

Heat Island effect

The sixth and last Criteria (C 6 - Heat Island Effect) is based on two aspects. In the first part, the hospital gets 1 point for each if: it has shading devices covered with solar panels, there are tree canopies or will be within 5 years of landscape installation, or the building has a correct orientation with a shading strategy. The second part is the ratio of covered car parks with tree canopies, solar panel canopies and underground parking in total. If the ratio is between 50-60%, the hospital gets 1 points. If the ratio is larger than 61%, the hospital gets 2 points. Overall the criteria is based on 6 points and the European average is 2.6 (43%) with median of 2.5 and mode of 4, while the Turkish average is 2 (33%) with median and mode of 2. San Stefano Hospital in Prato, Italy is the only hospital that has solar panel covered shadings which are on the open car parking space, and is the only hospital that got 1 point in the first part of the first aspect. Almost all of the European hospitals got 1 point each for the second and third micro criteria of the first aspects which are the tree canopies and correct orientation of the building with proper shading strategy. However, half of the hospitals could not get any point from the second aspect, covered car park ratio since many of those projects do not have any underground space for parking or any sort of shading device for the open car parks. Only the last 5 hospitals that started operating after 2014, either underground or covered open car parks. On the other hand, there are no Turkish hospitals that got points from the first section. However, all of the hospitals got full points (2 points) from the closed car park ratio since the majority of the car parking spaces in Turkish hospitals are underground (Figure 14 and 15).

Discussion

Site sustainability strategies and the relevance of assessment tools application

The study expands on the current knowledge about site sustainability as it is highly related with healthcare building design usually having huge environmental impact due to their functional and operational nature. On one hand, site sustainability criteria are strongly related to other sustainability dimensions such as decisions regarding transportation affect pollution problems (environmental impacts), fuel costs (economic impacts), equal availability and accessibility (social impacts) (24). On the other hand, the quality of site planning is directly related to healthcare structure design and also has a great effect on users' comfort and healing. Healthcare Site master planning is a powerful way to influence environmental design on health-related social norms at the population level and that various environmental design features at different scales such as regional land use and transportation planning, accessibility of public

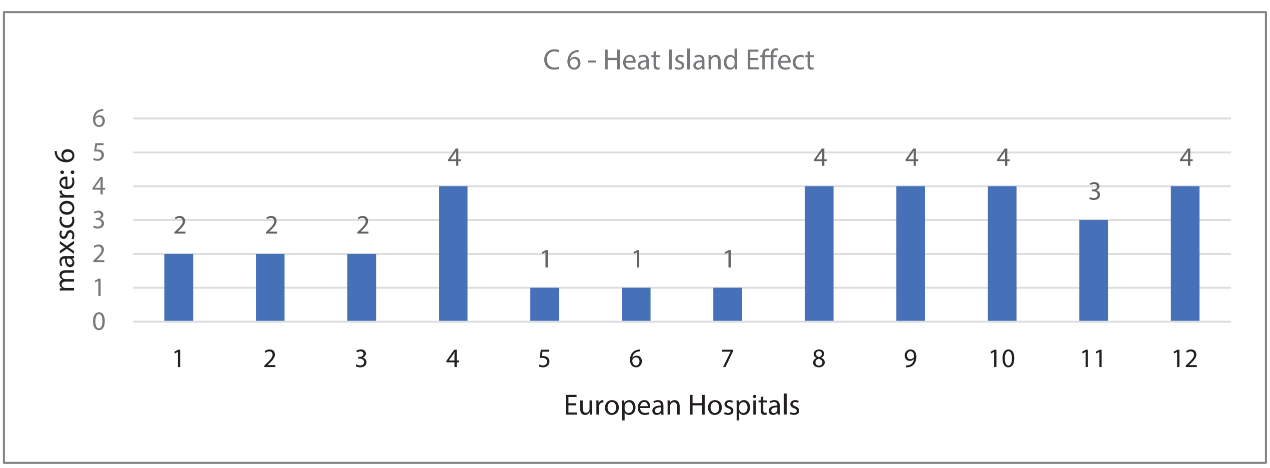

Figure 14. ATHOSS Macro Criteria 6 Points for European Hospitals.

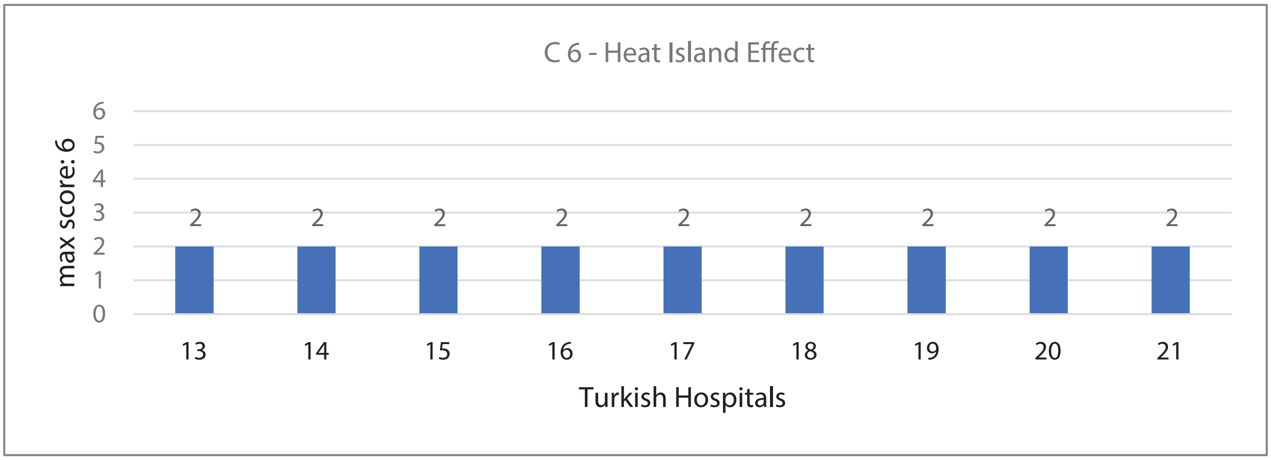

Figure 15. ATHOSS Macro Criteria 6 Points for Turkish Hospitals.

transit and building characteristics have influence on physical activity (25). There is an increasing tendency to apply these principles as comfortable site environment attributes (the amount and quality of green lands, wetlands, transportation availability and proximity, outdoor views) play an important role in environmental and social sustainability for users. Healthcare planners have an important role on understanding the basic principles of sustainability and implement them for enabling care to occur without harming the surrounding environment (14).

This analysis shows that on average Turkish City Hospitals gets general lower scores than European Construction Density and Community Connectivity (28%;50%), Alternative Transportation (18%; 50%), Site Development (26%; 38%). Connection to Natural World (30%; 52%) and Heat Island Effect (33%; 43%). Only in Development Density (30%; 16%) the score was higher. Moreover, it is noted that Gross Floor Area per bed ratio is much larger for Turkish City Hospitals which can be interpreted as one of the weaknesses related to overdesigning. When compared to European samples, there are some criteria that are remarkably weak in Turkish ones while some of the criteria does not have a direct relation with the country of the hospital. However, there are plenty of aspects that could be adapted from European ones to upgrade Turkish hospital projects. This detailed research showed that there are a wide range of points that could be improved or fixed for future projects or adaptations. For examples, economic critical ration highlight that hospital constructions are rather labor intensive and the relatively higher costs of European hospitals can be attributed to much higher labor cost in Europe compared to Turkey. The major reason behind the fact of large floor area per bed ratio is due to huge undefined spaces in Turkish hospitals left for commercial activities, common areas and the excessive covered car parking spaces. Although not spelled out explicitly, the construction companies, which are also owned by the concession companies, are being paid based on the area of the construction in Turkey. In order to increase the profit from the construction, the companies tend to build larger areas. As per the European standards, more hospital beds could be accommodated in the Turkish hospitals considering the construction areas. Overall the application of ATHOSS assessment tool is a first step for incorporating evaluation models and assessment methodologies in the process of design, planning and management of healthcare infrastructures in a European context. Several decisions are taken at policy-maker level for improving healthcare services and hospital real estate for the population but support tools are needed to based such complex decision on data and large scale application in a One Health perspective.

In particular the application of this tool is a preliminary step to enable the definition of some strategies that can support hospital managers, designers and decision-makers in implementing the site sustainability of their assets. This set of meta design strategies work as an optimization proposal for Turkish hospital samples. It is based on 6 macro criteria of ATHOSS and should this guideline be followed to the extent possible; the design would be naturally complied with site sustainability criteria of ATHOSS as an ideal scenario reaching high to top level of scores. The strategies can be classified as per their applicability during the planning and/or operational stages of the projects. Moreover, the strategies that are suitable to apply during the operational stage of the hospitals may also classified as low, medium and high complexity applications according to their technological criticality. This approach is aiming to guide the user depending on which stage of the project is and if the project is an already built operational one, it may help to prioritize the interventions.

Development density strategies

The study show that only one European and two Turkish hospitals got full points (2 points) on this section while two European and one Turkish hospital got half points (1 point). The other 15 hospitals could not get any points from this criteria since their ratio were below the defined limit. It means that all those hospitals have bigger gross floor areas than what is required as per ATHOSS or the site areas are small. This could be due to the access to only smaller lands in urban settlements, high building program requirements which increases the floor areas or over-design issues where more space is given to certain activities than needed.

For example, Royal London Hospital, St. Bartholomew's Hospital and New Karolinska University Hospital are all located inside dense city blocks and they are all vertical developments inside tower structures. This can be the reason why all these hospitals failed in the first criteria and got 0 point. On the other hand, Aarhus University Hospital in Denmark who got 2 points out of this criteria are a low density development health campus which works as a small town within itself with a hierarchy of roads, plazas and open green spaces.

The findings confirmed that the site localization is recognized as the pre-requirements for guaranteeing feasibility in hospital project developments as highlighted in literature (26,27). According to the different possible location of urban, semi-urban or rural area, hospital gross floor surfaces need to be adequately dimensioned retrospect to the overall site area in order to allow future expansion and adequate logistic flows (28,29).

Construction density and community connectivity strategies

The study shows that healthcare infrastructures in some country lack of connection and implementation of urban activities. A reason of this weakness could be that many of the Turkish hospitals are located far from city centers and any kind of urban settlements. They are all on non-developed parts of the cities and this results in not having enough complementary facilities around the hospitals. Some of them has commercial activities inside the hospital buildings but in many cases that is not enough to fulfill the defined requirement as per ATHOSS. The hospital complexity and multiple and diversity of users within the facility, along with the increasing requests for amenities, is gradually forcing hospital organization to increase their provision of supporting services dedicated to specific users, patient and customers also in light of serving a wide area of fraile population (30).This section indicates the maximum Construction Site Area and number of functions both inside and outside the project site (Classification: Planning Stage and Operational Stage depending on the project site conditions and size). Basic functions should be well connected and close to the hospital access either inside or outside the project site.

Alternative transportation strategies

The study highlight some best practices in terms of alternative transportation strategy; for example Royal London Hospital and St. Bartholomew's Hospital got full points (5 points) from this criteria. Both of the hospitals are located in central London and they are surrounded with many bus stops and underground stations. They also have minimal number of car parking spaces that encourages people to travel with mass transportation, that contributes to sustainability.

It is important to note that Turkish hospitals could not get any points from rail system. The reason is the lack of metro or underground systems in many cities in Turkey. Only in Ankara and Istanbul there is a rail system that passes close to the hospital project site areas. For Ankara, the rail stop is further than the criteria expectations and in Istanbul the metro stop is still not operational. The Turkish hospitals each got 1 point, with an exception of Eskisehir City Hospital that got 0 point from this criteria, either from bus stop proximity or the car parking space ratio. Last but not least, European average could be higher than the Turkish average as a result of hospital buildings being located closer to city centers or being inside already existing urban settlements with a working transportation network. The findings are coherent with several studies highlight that one of the barriers of healthcare access is the availability and affordability of transportation possibilities for reaching the hospital. Additionally, perceived distance and time burdens are mentioned as barrier to healthcare utilization (31,32). Hospital is a place where fragile users such as people with disabilities or reduced mobility, including patients with fragile health, must be able to easily access the service (33). Therefore hospital organization must provide sustainable and user-oriented strategies for reaching the building main entrance with specific regards to fragile and alternative or green users.

Site development strategies

Green roof, exterior green space and adequate ratio between indoor and accessible outdoor spaces must be provided in such large scale and complex development projects. In order to have operative ratio to be used the relationship should be calculated according to the total building footprint as well as the total site are.

It is recognised that guaranteend access to green space in hospitals has been shown to reduce emotional distress, improve mental health, increase socialization and community connection, increase physical activity, decrease cardiovascular and respiratory diseases, decrease pain management needs and hospital stay lengths and increase both patients' and staffs' overall satisfaction at the facility. Beyond benefiting those interacting with the hospital, green roofs have the ability to reduce the urban heat island effect, improve stormwater mitigation, increase biodiversity, and absorb toxins and pollutants through air filtration especially in urban hospitals (34). Despite literature and best practices stress the attention of green roof, the findings show that it is quite difficult to implement this strategy consistently in practice on large scale developments.

Connection to natural world and heat Island effect reduction strategies

After Roger Ulrich seminal research, several reviews and empirical studies highlighted the importance of visual environment in healthcare facilities as driving factors to improve occupants wellbeing, reduce stress and improve organizational productivity and efficiency (35,36). This strategies indicates also the ratio of courtyards and distance from water element which is recorded as an important features also in several studies in terms of patient preferences (37). Additionally it is important to reduce as much as possible large uncovered parking areas that may contribute to the phenomenon of Urban Heat Island but may be replaced with canopies, trees or eventually underground parking (38). The study highlights that having very generous courtyards and water elements in close proximity is a strategy that European hospitals are gradually adopting. On the contrary, providing covered car parking space seems challenging probably also due to the construction implications on such large size infrastructures.

Conclusions

Research outlooks

As the PPP Mega-Hospital model seems to be gaining further popularity in both developed and developing countries to realize sizable infrastructure projects, the site sustainability of these projects becomes even more important due to the huge impact on environment, economy and well-being of the population. Therefore, studies to understand and regulate the site sustainability issues are needed and becoming more essential. In this regard, future research could further enhance the validity of this study and open new windows for further research application.

Limitations and future developments

Starting from the results achieved, the following points are suggested for further research based on the limitations of this study, in particular:

- the sample group can be enlarged by including Mega-hospitals cases from a wider range of countries and regions worldwide;
- the aim of the paper was to test the tool on multiple cases without comparing health system differences and specific country regulation; future studies can develop a model that is also sensible to climate, regulatory and welfare system changes;
- the focus of the study was about site sustainability assessment therefore this evaluation should be intended and implemented as complementary to other sustainability measurement.

Acknowledgements: The authors would like to acknowledge the hospitals that participated in the study for the unconditional support and availability in providing the requested data. The authors would also like to acknowledge the participants in the Research Seminar / International Workshop "Healthcare Design and Evaluation" held at Politecnico di Milano in April 2022, organized with the support of DABC "Cultural Activities 2021" – proposer: Dr. Andrea Brambilla, DABC STRATEGIC LINE N° 1: Innovative projects for architecture, spaces and services: health, safety, inclusion, education and emergency for their relevant inputs on healthcare evaluation topic.

Ethic Committee: not applicable

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Author Contributions: Conceptualization, A.B., S.C. and L.E.; methodology, A.B.; formal analysis, L.E.; investigation, L.E.; writing—original draft preparation, L.E.; writing—review and editing, A.B.; supervision, S.C.; All authors have read and agreed to the published version of the manuscript.

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Received: 15 February 2023
Accepted: 16 April 2023
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