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Walkability and health – the relationship between built environment and the population's health status in the Metropolitan Area of Lisbon

Ramo Doutoramento de Urbanismo

Mauro Ricardo Fernandes Pereira

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Tese especialmente elaborada para a obtenção do grau de doutor

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Resumo

A falta de atividade física é um dos fatores mais importantes para o aumento de várias doenças crónicas. É reconhecido que andar a pé traz vários benefícios para a saúde e contribui para a prevenção de várias doenças. Por outro lado, a saúde é cada vez mais complexa, pois as questões do bem-estar e da saúde mental estão, felizmente, mais presentes nos dias de hoje. Vários estudos demostraram que as características do ambiente construído podem contribuir para a melhoria da saúde dos seus cidadãos, suportando estilos de vida mais saudáveis, em particular, estilos de vida mais ativos, com maior nível de atividade física. Um termo que tem sido usado para descrever o ambiente construído que suporta as deslocações a pé é o termo *walkability*. A tradução do termo mais sugerida é de "caminhabilidade". Das características que o conceito descreve fazem parte a qualidade dos caminhos pedonais, a morfologia urbana, o sentimento de segurança, a proximidade a pé de atividades, entre outros. Vários índices de caminhabilidade foram criados para medir as qualidades de ambiente construído, utilizando diferentes indicadores que descrevem essas qualidades. Porém, outras dimensões do ambiente construído são importantes para a melhoria da saúde e do bem-estar da população, que não são avaliadas pela maioria dos indicadores de caminhabilidade existentes, como, por exemplo, os impactos da qualidade do ar ou a proximidade a equipamentos de saúde. Por outro lado, grande parte da investigação foi feita para os contextos dos Estados Unidos da América, Canadá e Austrália, e alguns exemplos europeus, estando em falta o contexto mediterrâneo com as suas características próprias.

O presente doutoramento dá resposta a três grandes objetivos. Primeiro, a definição do conceito de caminhabilidade tendo em vista a sua relação com a saúde, incluindo não só a questão das deslocações pedonais, mas também o contributo do ambiente construído para outros aspetos do bem-estar e da saúde. Segundo, testa esta definição e os indicadores para a criação de um índice de caminhabilidade que explica a saúde para o contexto português. Finalmente, avalia a relação entre a caminhabilidade e a saúde, identificando formas e medidas de planear e desenhar cidades mais saudáveis e que promovam a saúde e bem-estar dos seus cidadãos.

A investigação segue uma abordagem de sucessivo aumento de detalhe, utilizando indicadores e medidas disponíveis e recolhidos a cada uma das escalas de análise. Na primeira escala, à escala da freguesia, os dados utilizados são principalmente dados oficiais e abertos, provenientes de fontes como o INE e outros organismos oficiais. A variável dependente é as admissões hospitalares devido a diabetes. Na fase seguinte, a análise é feita ao nível da subsecção estatística, avaliando-se a distribuição das características de caminhabilidade pelos vários grupos socioeconómicos na Área Metropolitana de Lisboa (AML). Nesta fase, foram criados e testados índices de caminhabilidade e de privação socioeconómica, sendo analisada a sua relação. Finalmente, na escala de maior detalhe, foram avaliadas características de desenho urbano ao nível da rua para o aumento das deslocações pedonais utilitárias e de lazer. A primeira abordagem nesta escala foi feita para Santarém, como forma de testar a metodologia a aplicar na AML. Na fase seguinte, foi aplicada uma abordagem semelhante para cerca de 1500 indivíduos em quatro concelhos da AML. Nesta última fase, foram avaliadas características de ambiente construído ao nível macro, que incluem acessibilidade ao centro da cidade de Lisboa, a equipamentos de saúde e de educação, entre outros; mas também foram usados indicadores de microescala importantes para a perceção do indivíduo, entre os quais a largura do passeio, densidade de árvores, segurança, entre outros. As características do ambiente construído foram usadas para procurar e explicar o nível de saúde dos indivíduos inquiridos.

Os resultados da primeira escala de análise mostram que não existe uma relação direta entre o ambiente construído e as admissões hospitalares. A influência é feita através da poluição do ar e do uso dos modos ativos. O modelo proposto explica 27% da variação das admissões hospitalares. Estes resultados revelam uma relação complexa entre o ambiente construído e a saúde, em particular, na sua relação de mediação com outras variáveis que são resultado das condições do ambiente construído, neste caso, a qualidade do ar e os modos ativos, intimamente ligados.

No caso dos resultados ao nível da subsecção, concluímos que não existe relação entre as condições socioeconómicas e as características de caminhabilidade na AML. Os diferentes grupos socioeconómicos ocupam os locais com melhores e piores condições de caminhabilidade. No entanto, considerando a distância ao centro da cidade, a zona dentro dos 15 minutos de distância do centro de Lisboa é aquela que apresenta os valores mais elevados no que respeita à correlação entre a caminhabilidade e as condições socioeconómicas. Neste caso, a correlação mais forte está presente entre o índice de caminhabilidade e o valor de propriedade, sendo este um importante *proxy* da condição socioeconómica.

Finalmente, os resultados dos testes metodológicos para a análise ao nível da rua no contexto de Santarém mostram que as condições da estrutura urbana, medida por indicadores de conectividade, é mais importante para explicar as deslocações pedonais.

Os resultados das várias escalas de análise reforçam a complexidade da relação entre o ambiente construído e a saúde dos habitantes. Os resultados destacam a importância das relações de mediação entre diferentes aspetos do ambiente construído e os hábitos dos indivíduos, em particular na questão da mobilidade com impactos na qualidade do ar e nos níveis de atividade física. Por outro lado, os resultados questionam a vantagem da criação de indicadores compostos com base em condições de caminhabilidade e da sua real utilidade para quem planeia e desenha cidade. Os indicadores compostos são úteis para a avaliação do desenho proposto, mas o contributo individual de cada aspeto do ambiente construído às diferentes escalas é o mais útil para o apoio ao desenho e planeamento da cidade.

O presente doutoramento confirma a importância do ambiente construído para a saúde da população, em particular no que respeita à mobilidade ativa. Por outro lado, dá também pistas para os que arquitetos que desenham a cidade o possam fazer de forma a promover uma cidade e cidadãos mais saudáveis.

Palavras-chave

caminhabilidade, saúde, ambiente construído, indicadores urbanos

Abstract

Lack of physical activity is one of the most important factors that influences several chronic diseases increase. It is recognized that walking has several health benefits and contributes to the prevention of several diseases. On the other hand, health is becoming more and more complex with issues of well-being and mental health more relevant nowadays. Several studies have shown that built environment characteristics can contribute to improving citizens' health by supporting healthier lifestyles, in particular, more active lifestyles with higher levels of physical activity. The term walkability has been used to describe the built environment that supports walking. The characteristics that the concept describes include quality of pedestrian paths, urban morphology, feeling of safety, proximity to activities on foot, among others. Several indexes of walkability have been created to measure the qualities of the built environment, using different indicators that describe these qualities. However, other built environment dimensions are important to improve the health and well-being of the population, and these are not assessed by the majority of the existing walkability indicators. Some examples are air quality impacts or proximity to health facilities. On the other hand, much of the research has been done for the United States of America, Canada and Australia, as well as some European examples, but the Mediterranean context, with its own characteristics, is missing.

This PhD responds to four major objectives. First, to define the concept of walkability in view of its relationship with health, not only including the issue of pedestrian travel, but also the contribution of the built environment to other aspects of well-being and health, which include chronic diseases, more specifically, diabetes. Second, to test this definition and the indicators to create a walkability indicator that explains health for the Portuguese context. Third, to identify which health indicators are related to built environment. Finally, to evaluate the relationship between walkability and health, and identifying ways and measures to plan and design healthier cities that promote citizens' health and well-being.

The research follows an approach of successive increase in detail, using indicators and measures available and collected at different scales of analysis. At the first scale, the parish scale, the data used are mainly from official and open data sources, such as INE and other official institutions. The dependent variable is hospital admissions due to diabetes. In the next stage, the analysis is done at the census block level, assessing the distribution of walkability characteristics across the various socioeconomic groups in the Lisbon Metropolitan Area (LMA). In this phase, indexes of walkability and socioeconomic deprivation were created and tested, and their relationship was analysed. Finally, at the scale of greater detail, urban design features at the street level were evaluated to increase utilitarian and leisure pedestrian trips. The first approach at this scale was done for Santarém, as a way to test the methodology to be applied in LMA. In the next stage, a similar approach was applied to about 1500 individuals in four municipalities of LMA. In this last phase, built environment characteristics were evaluated at the macro level, including accessibility to Lisbon city centre, health and education facilities, among others; however, micro scale indicators were also important to evaluate individual's perception, including sidewalk width, tree density, safety, among others. The built environment characteristics were used in an attempt to explain the level of health of the individuals surveyed.

The results of the first scale of analysis show that there is no direct relationship between built environment and hospital admissions. The influence happens through air pollution and the use of active modes. The proposed model explains 27% of the variation in hospital admissions. These results reveal a complex relationship between built environment and health, in particular, in its mediating relationship with other variables that are a result of the built environment conditions, in this case, air quality and active modes, closely linked.

In the case of the census blocks level results, we conclude that there is no relationship between socioeconomic conditions and walkability characteristics in LMA. The different socioeconomic groups occupy locations with the best and worst walkability conditions. However, considering the distance to the city centre, the area within 15 minutes away from downtown Lisbon is the one that presents the highest correlation between walkability and socioeconomic conditions. In this case, the strongest correlation exists between the walkability index and property value, which is an important proxy of socioeconomic condition. Finally, the results of the street level analysis show that the condition of the urban structure, as measured by connectivity indicators, is more important to explain pedestrian trips.

The results from the various scales of analysis reinforce the complexity of the relationship between the built environment and the inhabitants' health. The results support the importance of mediation relations between different aspects of the built environment and the individual habits, particularly in the issue of mobility, with impacts on air quality and levels of physical activity. On the other hand, the results cast a doubt on the advantage of creating composite indicators of walkability conditions and their real usefulness for those who plan and design cities. The composite indicators are beneficial for the evaluation of the proposed design, but the individual contribution of each aspect of the built environment at different scales is the most valuable for supporting city design and planning.

This PhD confirms the importance of the built environment for the health of the population especially in aspects of active mobility. Moreover, it also gives clues for architects who design the city to do so in order to promote a healthier city and citizen.

Keywords

walkability, health, built environment, urban indicators.

Índice

Lista de abreviaturas

AML: Área Metropolitana de Lisboa

FCT: Fundação para a Ciência e Tecnologia

INE: Instituto Nacional de Estatística

OMS: Organização Mundial de Saúde

SES: Estatuto socioeconómico

SIG: Sistema de Informação Geográfica

SMAILE: Saúde Mental - Avaliação do Impacte das Condicionantes Locais e Económicas

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1 Introdução

A localização das cidades, desde o seu início, é feita com base na preocupação com a saúde e bem-estar dos seus habitantes. Desde os primórdios das cidades, a proximidade a recursos como a água e a sua exposição e orientação aos ventos são preocupações presentes como forma de promover o bem-estar e a saúde dos seus habitantes (Frumkin, Frank, & Jackson, 2004; Lamas, 1993). Importantes intervenções urbanísticas que ficaram na história do urbanismo procuraram criar cidades mais salubres, com melhor qualidade de vida, tentando resolver os problemas das cidades medievais (Cassedy, 1962). O plano de Cerdá é um exemplo dessas intervenções, procurando criar mais salubridade à cidade de Barcelona (Clelia & Costa, n.d.). Na história mais recente, a introdução do automóvel trouxe transformações radicais no planeamento das cidades, o que trouxe novas ameaças à saúde e bem-estar da população (Dannenberg, Frumkin, & Jackson, 2011). O desenvolvimento de subúrbios urbanos monofuncionais, altamente dependentes do automóvel com uma maior distância às principais atividades do dia a dia, levou a uma redução das deslocações a pé, com impactos na saúde da população (Frumkin et al., 2004). O paradigma do automóvel como mote para o planeamento das cidades manteve-se durante vários anos com a criação de aglomerados completamente dependentes do automóvel, sendo os Estados Unidos o maior exemplo, embora todas as grandes cidades do mundo seguissem esta tendência (Giles-Corti et al., 2016; Saelens, Sallis, & Frank, 2003).

Os vários problemas criados pela dependência automóvel colocaram no centro das várias agendas públicas a necessidade de alteração deste paradigma. O desenvolvimento urbano sustentável ganhou importância nas agendas internacionais (UN - Habitat, 2016; World Health Organization Regional Office for Europe, 2016). Uma das formas de alcançar esse desenvolvimento sustentável é através do desenho de espaços urbanos mais caminháveis (Patel et al., 2018; World Health Organization., 2017). O desenho urbano mais caminhável permite a criação de espaços de interação social e o aumento das deslocações a pé, o que pode levar a um estilo de vida mais saudável (Badland et al., 2014; Hajna et al., 2015; Saelens et al., 2003; Zapata-Diomedi & Veerman, 2016). A avaliação das características do ambiente construído, segundo a sua capacidade de promover as deslocações a pé, tem sido feita através de índices que descrevem a sua “caminhabilidade”, conceito traduzido do inglês, *walkability*. Nos últimos anos tem havido grande interesse sobre este conceito, surgindo várias investigações que propõem diferentes formas e ferramentas para medir a caminhabilidade do ambiente construído (De Vos, Lättman, van der Vlugt, Welsch, & Otsuka, 2023; Hajna et al., 2015; H. Wang & Yang, 2019). Nessas ferramentas encontramos a definição dos indicadores que podem compor os índices de caminhabilidade. Por outro lado, a avaliação da caminhabilidade também tem sido feita a diferentes escalas de análise. As ferramentas utilizadas são bastante diversificadas: existem aquelas que recorrem a inquéritos à população para avaliar a sua perceção do ambiente construído (Leslie et al., 2005; Nielsen & Winther, 2019; Toma, Hamer, & Shankar, 2015), e outras que utilizam indicadores quantitativos que descrevem os aspetos do ambiente construído para as deslocações a pé (Cerin et al., 2018; Shatu, Yigitcanlar, & Bunker, 2019).

Os vários estudos, como os que têm sido desenvolvidos pelo *International Physical Activity and the Environment Network – IPEN* em várias cidades do mundo, têm demonstrado o contributo de espaços mais caminháveis para diferentes aspetos da saúde e bem-estar da população. O principal contributo prende-se com o aumento dos níveis de atividade física, com impacto nos níveis de obesidade, causa de várias doenças. Por outro lado, espaços mais caminháveis promovem uma maior interação social com benefícios para a saúde mental e para o bem-estar da população (Liu et al., 2019; Tzoulas et al., 2007; Zhang, Mavoa, Zhao, Raphael, & Smith, 2020). Outro contributo importante decorrente da criação de espaços mais caminháveis é a redução da necessidade da utilização do automóvel, com impactos positivos na diminuição dos níveis de poluição desses locais, que são a causa de várias doenças e mortes nas cidades modernas (Marshall, Brauer, & Frank, 2009).

Muita investigação sobre o impacto de espaços mais caminháveis na saúde e bem-estar da população tem sido feita em contexto norte-americano e em cidades do Canadá e da Austrália (Arcaya et al., 2016; Badland et al., 2014; Gadais, Boulanger, Trudeau, & Rivard, 2018; Saelens & Handy, 2008). É possível encontrar alguns exemplos do continente europeu que usam e adaptam alguns dos indicadores e ferramentas utilizadas (Buehler, Kuhnimhof, Bauman, & Eisenmann, 2018; Grasser, van Dyck, Titze, & Stronegger, 2017), porém, a investigação no contexto português é ainda reduzida. Exemplos no contexto português são a investigação sobre a influência das características do ambiente construído nos níveis de obesidade (Santana, Santos, & Nogueira, 2009) e na saúde mental da população (Loureiro, Costa, Almendra, Freitas, & Santana, 2015; Loureiro, Santana, Nunes, & Almendra, 2019; Santana, Costa, Cardoso, Loureiro, & Ferrão, 2015; Zuniga-Teran et al., 2017). Relacionado com este aspeto, a cidade do Porto esteve envolvida no estudo internacional promovido pelo *IPEN- International Physical Activity and the Environment Network,* que relacionou as características do ambiente construído com os níveis de atividade física (Pizarro, Santos, Ribeiro, & Mota, 2012). Neste âmbito, foram elaborados indicadores para a descrição do ambiente construído que potenciam as deslocações a pé e que podem influenciar a escolha do modo de transporte. Também em Lisboa foram desenvolvidos alguns indicadores de caminhabilidade (Cambra, 2012; Cambra & Moura, 2020; Moura, Cambra, & Gonçalves, 2017).

No entanto, a questão da saúde vai para além da atividade física e da ausência de doença. Como a Organização Mundial de Saúde (OMS) descreve, a saúde será "*um estado de completo bem-estar físico, mental e social e não somente ausência de infeções e enfermidades*" (World Health Organization, 1986). O conceito de saúde definido pela OSM tem uma caracter mais abrangente e que se relaciona melhor com a definição de bem-estar (Kent, Ma, & Mulley, 2017). Relacionado com este aspeto foram desenvolvidos vários indicadores de bem-estar da população que incluem não só o bem-estar físico, mas também o mental (World Health Organization, 1986). Com o objetivo de descrever os aspetos do ambiente construído que promovem o bem-estar, foram criados indicadores de "liveability". Muitos desses indicadores incluem características de caminhabilidade como dimensão fundamental para esse bem-estar (Badland et al., 2014; Hooper et al., 2020).

Apesar dos trabalhos referidos anteriormente para o contexto português, o autor desta tese não tem conhecimento de estudos que avaliem o impacto da caminhabilidade no bem-estar da população. A investigação aqui desenvolvida pretende contribuir para colmatar algumas lacunas no conhecimento sobre o tema em destaque, na perspetiva do arquiteto e para arquitetos e urbanistas. Desta forma, identificar as características do ambiente construído que estes profissionais podem alterar de forma a influenciar a saúde e bem-estar da população para um contexto territorial onde vivem perto de três milhões de habitantes.

2 Questões de investigação e objetivos

O conceito da caminhabilidade tem sido amplamente discutido nos últimos anos em várias áreas do conhecimento, desde o planeamento e desenho urbano até às questões da saúde. Contudo, os especialistas envolvidos são de áreas do conhecimento e tem pontos de vista específicos. O presente trabalho tem como objetivo geral analisar, da perspetiva do arquiteto, como as características das cidades influenciam a saúde da população. A tese pretende responder a três questões:

Q1. Quais as componentes de um ambiente caminhável que contribuem para a saúde da população?

Q2. De que forma se medem esses componentes para o contexto português?

Q3. Como se relacionam as dimensões de um ambiente caminhável com os diferentes aspetos da saúde e bem-estar da população?

Tendo como referência o objetivo geral de perceber como as características da cidade influenciam a saúde da população e procurando responder à três questões de investigação, foram identificados três objetivos.

O1 - O primeiro é a criação de um indicador de caminhabilidade que avalie as características do ambiente construído, que influenciam a saúde da população, e que sirva da ferramenta para arquitetos e urbanistas no planeamento das cidades.

O2 - O segundo objetivo é testar e adaptar o indicador proposto no contexto português, em particular à AML, tendo em conta a sua diversidade territorial e socioeconómica.

O3 - Finalmente, o terceiro objetivo é avaliar a relação entre o conceito de caminhabilidade e os indicadores de saúde. Desta forma, pretende-se identificar quais os aspetos das condições do ambiente construído que influenciam os indicadores de saúde definidos e o tipo de relação direta e/ou indireta que existe entre eles. Com os resultados será possível definir políticas de intervenção e planeamento no território que levem à melhoria da saúde da população.

Para dar resposta a estes objetivos foram desenvolvidos cinco artigos científicos que sistematizam os resultados da investigação.

Tabela 1 - Objetivos específicos da investigação em articulação com os artigos científicos resultantes do projeto de doutoramento

	Q1	**Q2**	**Q3**
Artigo	**O1 Criação de indicador de caminhabilidade**	**O2 Testar e adaptar o indicador proposto ao contexto português**	**O3 Relação entre a caminhabilidade e a saúde**
I. A relação entre walkability *e a saúde na Área Metropolitana de Lisboa – a sua relação direta e indireta*			**X**
II. The relationship between built environment and health in the Lisbon Metropolitan area – can walkability explain diabetes' hospital admissions?			**X**
III. The contribution of a walkable environment to a sustainable and equity city – the Lisbon Metropolitan Area	**X**	**X**	
IV. The contribution of design dimension for utilitarian and leisure walking – the relative influence of connectivity measures and streetscape features	**X**	**X**	
V. The relationship between the population's socio-economic status and walkability measures: The context of the Lisbon Metropolitan Area	**X**	**X**	

2.1 Estrutura da tese de doutoramento

A investigação empírica segue uma abordagem de sucessivo aumento do detalhe de aproximação ao território em análise. Seguindo a abordagem da Faculdade de Arquitetura, ambiciono adaptar a escala da cidade à escala da mão. Por este motivo, as análises empíricas às várias escalas do território utilizam as diferentes ferramentas de análise ao dispor do arquiteto e urbanista. A análise empírica tem como escalas de referência, primeiramente, os limites administrativos, inicialmente para as freguesias, e depois para as subseções estatísticas, e, à medida que o detalhe aumenta, é a perceção individual do utilizador da cidade que dita a escala de análise. As escalas de análise traduzem, num primeiro nível, a noção do bairro e, posteriormente a escala da rua que o envolve.

A tese está dividida em cinco capítulos: 1) Estado da arte, que contextualiza e enquadra o tema e o objeto de estudo, em particular, através dos conceitos de saúde da população e o papel das cidades na saúde; 2) metodologia utilizada da investigação, descrevendo a abordagem adotada na investigação; 3) Resultados da investigação, onde se incluem os cinco artigos produzidos no âmbito da investigação; e 4) Discussão das principais conclusões, sistematizando-as às luz do objetivos do doutoramento, finalmente, um 5) com as conclusões do doutoramento.

3 Estado da Arte

O capítulo do estado da arte da literatura tem como ponto de partida dois grandes conceitos - o conceito da saúde e o do ambiente construído - e de como estes se relacionam para explicar os níveis de saúde ou bem-estar. Num primeiro momento, faz-se uma breve descrição da evolução histórica do urbanismo e de como as cidades foram planeadas com vista à promoção e salvaguarda da saúde pública até aos dias de hoje. É ainda descrita a forma como as cidades modernas ainda concentram vários problemas de saúde e como estas se têm mostrado capazes de influenciar a qualidade de vida dos seus cidadãos. Num segundo momento, é apresentado o conceito de saúde e de como vários modelos ecológicos foram sendo desenvolvidos para explicar os resultados em saúde.

A cidade e o ambiente construído que a define influenciam os hábitos e estilo de vida dos seus habitantes. Concretamente, os espaços desenhados para promover as deslocações a pé permitem o aumento de atividade física em resultado do uso dos modos de transporte ativo, a pé, de bicicleta e de transporte públicos (De Vos et al., 2023; Saelens et al., 2003). Desta forma, e com o aumento dos níveis de atividade física, é possível reduzir os níveis de obesidade, principal causa das doenças não comunicáveis, que são uma das principais causas de morte nos dias de hoje (WHO, 2014). Por outro lado, espaços caminháveis e amigos do peão permitem uma maior interação entre indivíduos, o que contribui para o aumento do capital social e do sentimento de pertença, importante para a saúde mental (Hassen & Kaufman, 2016).

No ponto seguinte, é apresentado a definição de espaço caminhável, e de como é complexa a sua medição, sendo apresentadas as várias metodologias e indicadores utilizados para este fim. Seguidamente, é discutido como as condições socioeconómicas são importantes para os níveis de saúde e bem-estar dos indivíduos. Uma componente importante dessa discussão é a forma como diferentes grupos socioeconómicos ocupam diferentes áreas da AML com diferentes condições de caminhabilidade. Finalmente, é apresentado o estado da arte para o contexto português e como este justifica o interesse e importância da presente investigação.

3.1 A evolução da história da saúde nas cidades

No século passado, a urbanização constituiu uma das mudanças demográficas mais importantes a nível mundial e representa uma alteração substancial em relação à forma como a maioria da população mundial tem vivido nos últimos milhares de anos, já que a população deixa os campos e concentra-se nas cidades (Galea & Vlahov, 2005). Esta grande mudança ocorre na cidade industrial, onde as pessoas se aglomeram na cidade, criando graves problemas de saúde e salubridade, levando às grandes epidemias nas cidades. Por outro lado, as áreas fora da cidade são conotadas com a saúde e o bem-estar (Frumkin et al., 2004). Atualmente, mais de 50% da população vive em cidades. O crescimento global da população nos próximos 30 anos será principalmente nas cidades (UN - Habitat, 2020). Esta nova realidade trará complexos desafios à gestão das cidades nas várias áreas, desde a mobilidade, à gestão dos vários equipamentos com impactos na saúde e bem-estar dos seus habitantes (Giles-Corti et al., 2016).

As primeiras cidades da história do urbanismo mostram preocupações com a saúde no desenho da sua ocupação, por exemplo, relacionados com a sua localização em lugares próximos de fontes de água, mas também revela preocupações com as orientações face aos ventos dominantes como forma de higienizar a cidade. Durante os séculos XVII e XVIII, o conhecimento científico teve um forte desenvolvimento com a ideologia "higienista", preocupada em melhorar a saúde e o bem-estar na cidade industrializada (Lamas, 1993; Salgueiro, 2001). A contínua degradação das condições de saúde nas cidades industriais levou ao surgimento de planos urbanos para alterar o desenho medieval das cidades. Esses novos planos sugerem a alteração do traçado medieval para um traçado ortogonal, com ruas largas, promovendo a renovação do ar e a introdução de infraestruturas sanitárias mais eficazes (Barton, 2017). França esteve na linha da frente destes movimentos com o exemplo do projeto *Haussmann* para Paris (Barton, 2017; Frumkin et al., 2004; Lamas, 1993). Face a estes problemas nas cidades, vários autores teorizaram sobre os modelos e planos de desenvolvimento das cidades que eliminem estas questões. Desta discussão, surgiram novas teorias de planeamento para a criação de novas cidades. Isto inspirou as cidades utópicas de diferentes planeadores e arquitetos e urbanistas.

"A cidade jardim", defendida por Howard, sugere a criação de uma cidade jardim para responder à ideia de uma cidade saudável, combinando as vantagens do lugar rural e da cidade, eliminando os problemas das cidades industriais. Howard defende aspetos da topografia, as exposições ao sol e a orientação das eixos dominantes para alcançar uma cidade mais confortável e à escala humana (Lamas, 1993). A *"Broadacre City",* proposta por Frank Lloyd Wright no seu livro "*The Disappearing City*" (1932), combina a ideia de arquitetura orgânica e comunidade com as ideias da cidade jardim. Os dois exemplos anteriores são soluções para as novas cidades e não uma solução para a transformação das cidades existentes. Outro exemplo é o "*La Ville Radieuse*", de Le Corbusier (1964), baseada na ideia do movimento moderno e da Carta de Atenas, onde é defendida a separação das diferentes funções da cidade - a "máquina viva". As teorias aspiram à orientação e às mudanças do modo de vida da população com um total saneamento social, revelando-se uma imposição de modos de vida em que, por exemplo, todos terão um carro. Em termos de conceção urbana é dada uma forte importância aos modos de transporte individuais e um enorme espaço público para a interação comunitária.

Atualmente, está em estudo um novo projeto futurista localizado na Arábia Saudita chamado "*The Line*". O projeto, liderado por Antoni Vives, procura promover uma nova forma de ocupação concentrada numa estrutura linear com 170km de extensão e 200m de largura ("THE LINE: a revolution in urban living," n.d.). Nesta estrutura, a população estará organizada em comunidades, com preocupações de promoção do bem-estar e onde o acesso às principais atividades é feito num raio de cinco minutos a pé. As deslocações tiram partido das novas tecnologias de mobilidade autónoma e a acessibilidade aos vários pontos da estrutura não ultrapassará os 20 minutos. A estrutura projetada permitirá a reutilização dos recursos, tornando a sua pegada neutra em carbono. Um protótipo do que será uma cidade sustentável é também o projeto da Masdar City no Emirado de Abu Dabi, onde todo o desenho da cidade e dos seus edifícios procura minimizar o consumo de energia.

Ao longo da história, a preocupação da promoção da saúde e bem-estar dos indivíduos nas cidades foi uma constante. As metodologias e ferramentas usadas foram diferentes e com resultados distintos. Atualmente, é consensual que o desenvolvimento das cidades suportado no modo motorizado trouxe várias dificuldades para a promoção de uma cidade mais caminhável (Giles-Corti et al., 2016; Saelens et al., 2003). O impacto é evidente considerando a grande dependência automóvel em grande parte das cidades e, em particular, na AML (Santana et al., 2009; Santos, 2017). Essa grande dependência tem consequências na saúde devido ao maior tempo sentado nos modos motorizados (Yang & French, 2013), à deterioração da qualidade do ar (Frank et al., 2006), e à redução do espaço público dedicado às pessoas.

3.2 O conceito de saúde

O ambiente construído tem impacto na saúde da população, atuando, positiva e negativamente, na promoção de hábitos de vida (Mueller et al., 2015; Santana et al., 2009). No entanto, o conceito de saúde é complexo e não diz apenas respeito à ausência de doença, mas a um sentimento de bem-estar que envolve aspetos físicos e emocionais (Santana, 2014).

No sentido de explicar o estado de saúde do indivíduo foram desenvolvidos vários modelos que identificam os principais determinantes da saúde. O primeiro modelo foi desenvolvido por Dalhlgren e Whitehead (1991), reproduzido na Figura 1. Neste modelo, os autores definem quatro níveis de intervenção. O primeiro, mais afastado do indivíduo, descreve a estrutura ambiental que contempla a estrutura do país e a sua economia. O segundo diz respeito à componente ambiental e económica das características da área de residência e da área envolvente ao local de trabalho do indivíduo. O terceiro nível é a comunidade de suporte individual, onde se inclui a comunidade onde se insere e a sua rede de amigos. O último nível está intimamente ligado às características físicas e emocionais do indivíduo, incluindo os seus hábitos e estilos de vida, como alimentação, atividade física, etc. É consensual que as características individuais são a dimensão que mais contribui para a situação de saúde individual, porém, como o modelo descreve, as vários escalas de contexto influenciam as condições individuais, em particular, os seus hábitos, que, por sua vez, influenciam a saúde individual. A identificação e descrição dos vários níveis de contexto permite o desenvolvimento de políticas para a promoção e proteção da saúde a diferentes escalas (ver Figura 1).

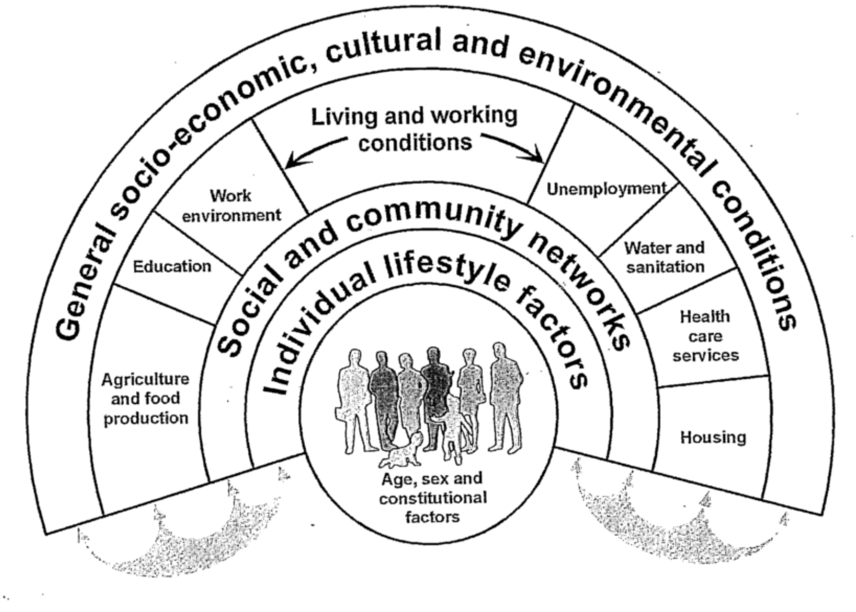
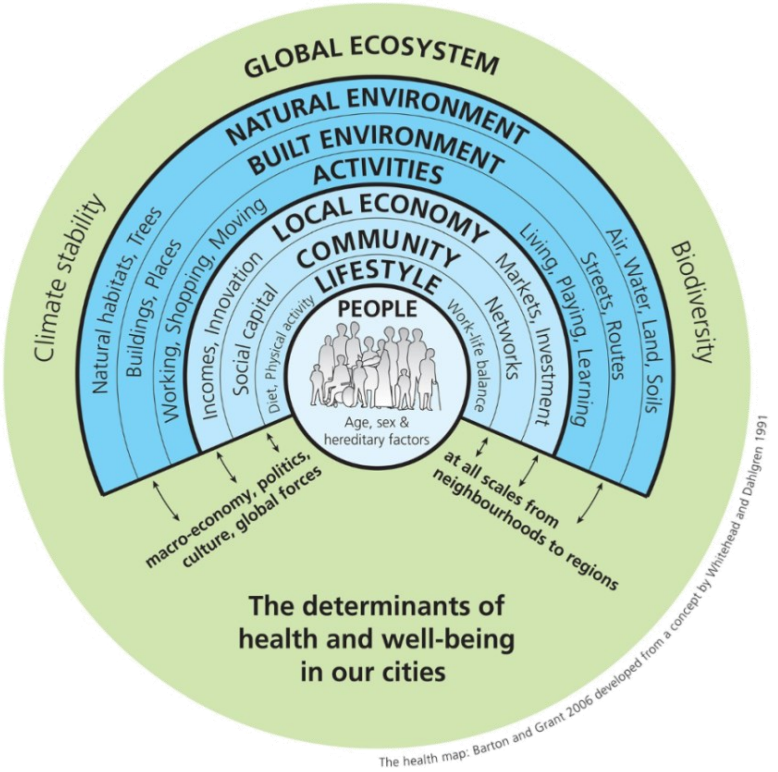


Figura 1 - Modelo dos principais determinantes em saúde segundo Dalhlgren e Whitehead (1991)

O modelo de Dalhlgren and Whitehead (1991) foi posteriormente desenvolvido em 2006 por Barton e Grant (2006), como consta na Figura 2. Neste novo diagrama, foram incluídas teorias ecológicas e de desenvolvimento sustentável. O objetivo foi criar uma ferramenta visual para comunicação e análise dos vários contextos e a sua relação/impacto com a/na saúde. O modelo desenvolvido contou com a contribuição de vários especialistas (Barton & Grant, 2006). O seu desenho procura ser uma ferramenta dinâmica que promove a interação entre especialistas de várias áreas, como urbanistas, agentes públicos de saúde, ecologistas e arquitetos, combinando várias áreas do conhecimento, sejam elas as áreas do transporte, da qualidade do ar, ou do desenvolvimento sustentável. Os determinantes da saúde são representados por vários arcos ou camadas que representam os diferentes níveis do contexto do individuo. O centro do diagrama é ocupado pelo próprio indivíduo, a primeira camada do contexto, até à última camada de contexto formada pelo ecossistema global onde vivemos. As três primeiras camadas de contexto são formadas pelas características diretamente relacionadas com a biologia física mental do indivíduo e onde este tem o mesmo tipo de influência. As seguintes três camadas são os contextos de vizinhança que influenciam o bem-estar. A última camada é o ecossistema global que inclui o contexto natural, a biodiversidade e as mudanças climáticas. Os autores sugerem como lugar do urbanista a esfera do Ambiente Construído, a azul-escuro (os três arcos exteriores do meio-círculo), onde a atividade dos arquitetos e urbanistas pode ter influência nos determinantes da saúde.



The health map: Barton and Grant 2006 developed from a concept by Whitehead and Dahlgren 1991

Figura 2- Diagrama da saúde segundo Barton e Grant (2006)

O diagrama de saúde de Barton e Grant está na base da operacionalização de diversos projetos de investigação e programas de saúde pública. Os determinantes de saúde e bem-estar nas cidades são avaliados com base no impacto nos resultados de saúde como mortalidade e morbilidade.

As figuras seguintes mostram diferentes diagramas que representam a operacionalização do modelo em diferentes programas e que serviram de referência para a criação do meu próprio modelo de investigação.

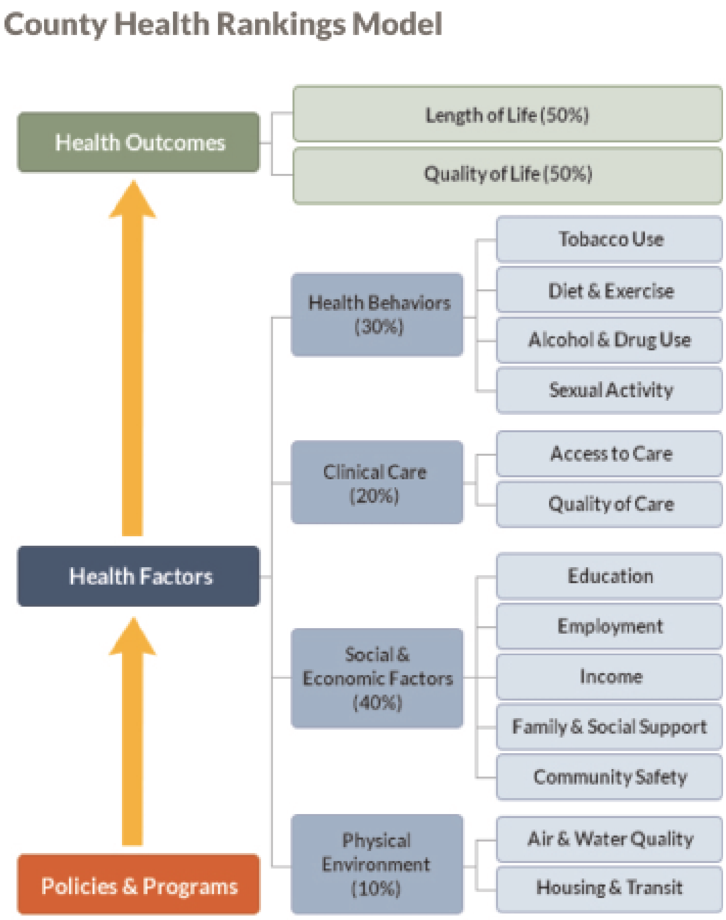


Figura 3 - County Health Ranking (R. Wood and Foundation 2014)

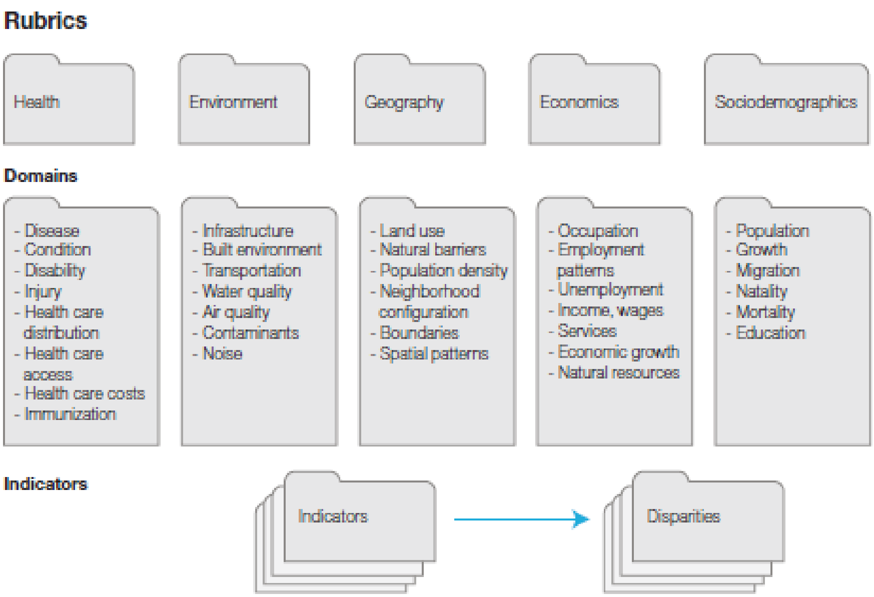


Figura 4 - Modelo para a classificação de medidas de saúde urbana (World Health Organization, 2014)

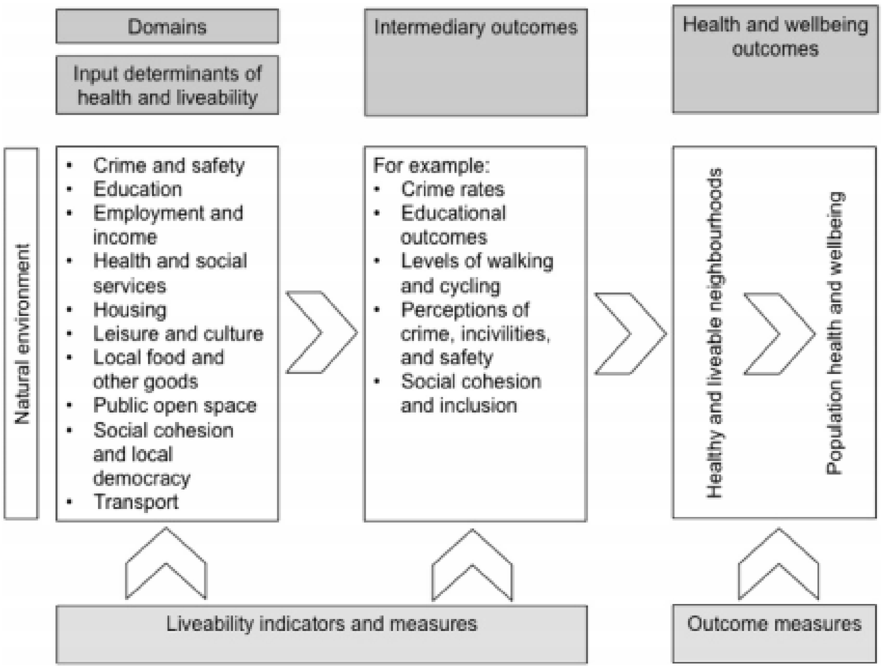


Figura 5 - Linhas de causalidade para o "*liveability*", compreendendo os determinantes de saúde e os resultados intermédios e finais na saúde e bem-estar (Badland et al., 2014)

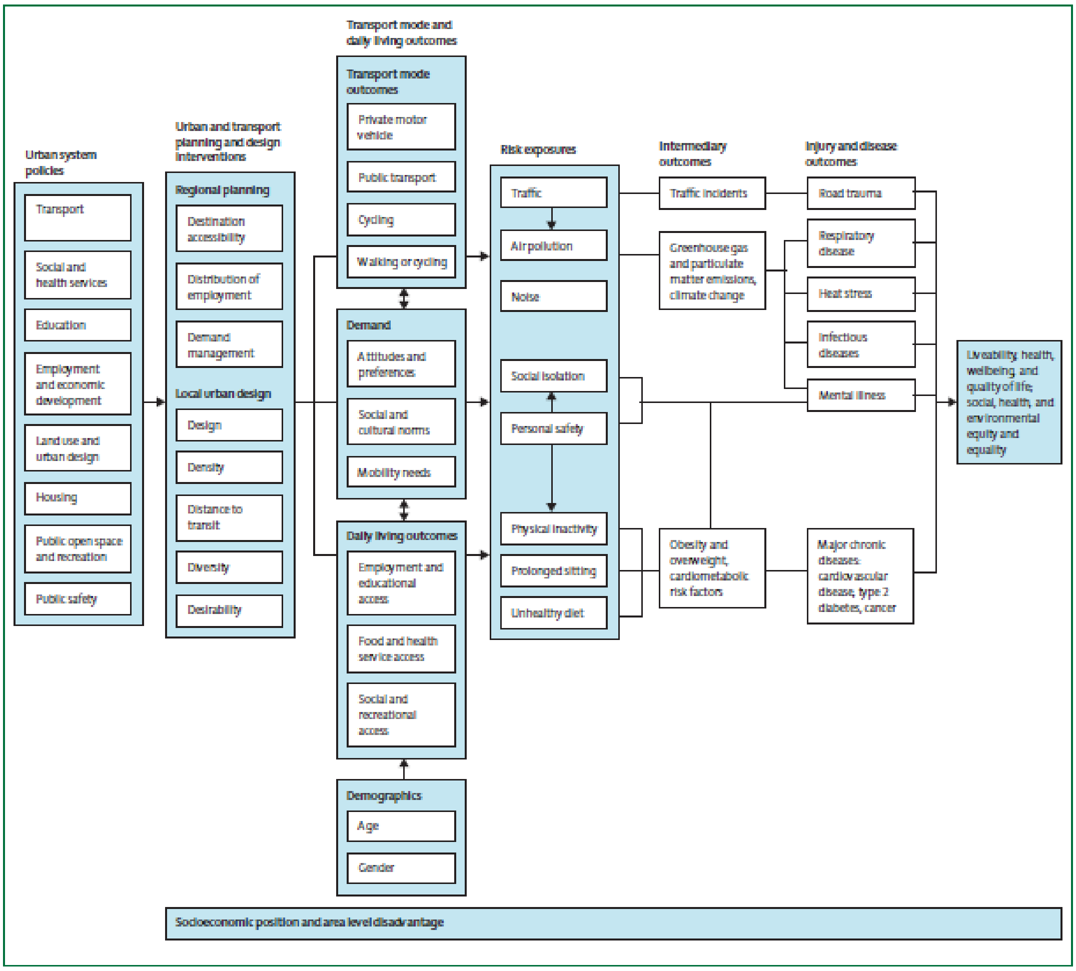
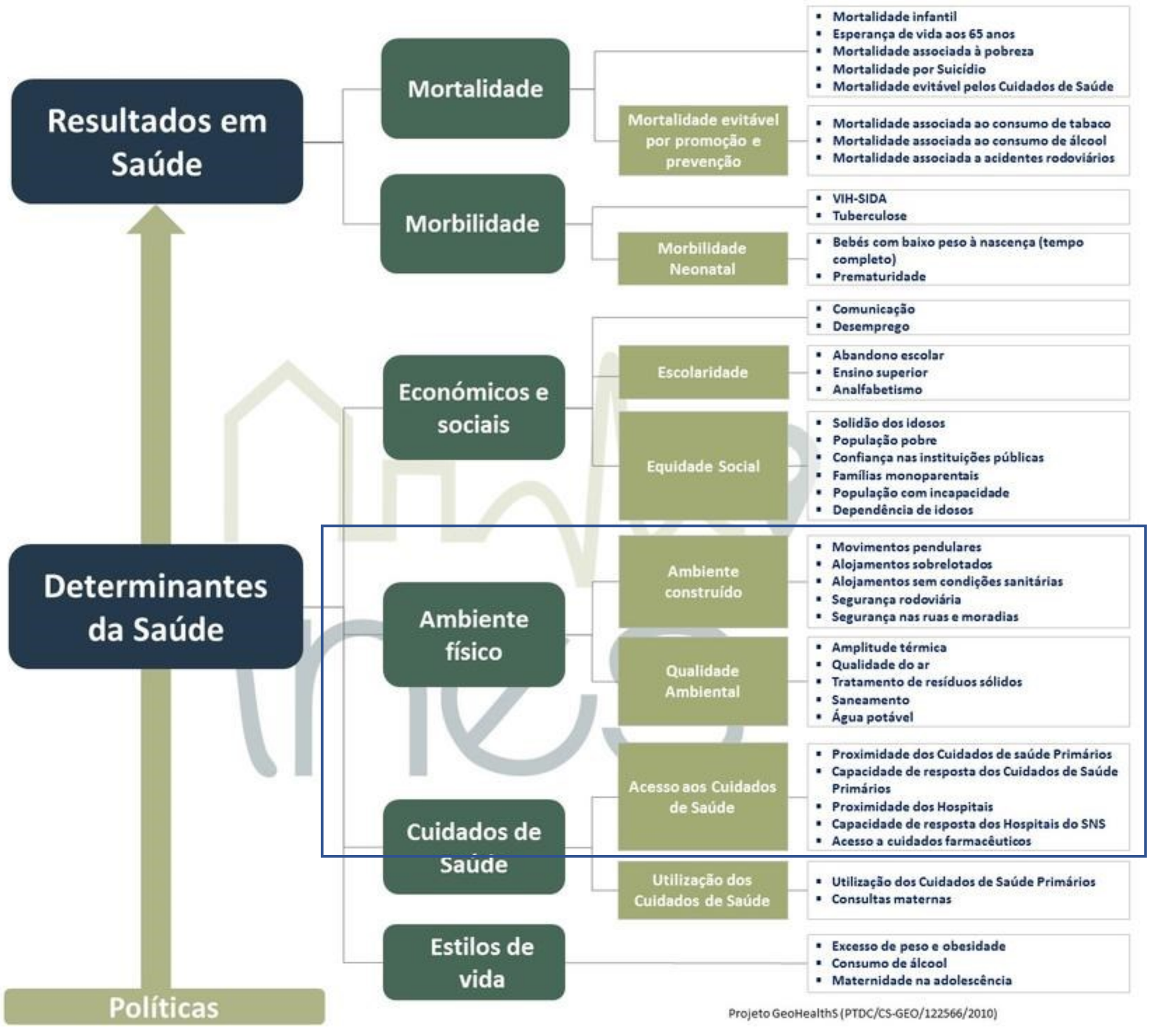


Figura 6 - Efeitos diretos e indiretos que as decisões no planeamento urbano e dos transportes tem na saúde e bem-estar (Giles-Corti et al., 2016)



Projeto GeoHealthS (PTDC/CS-GEO/122566/2010)

Figura 7 - Estrutura global do índice de saúde da população desenvolvido para Portugal (Santana, 2015)

As várias dimensões e estruturas de enquadramento são operacionalizadas por diferentes indicadores que variam nas áreas de conhecimento e possuem técnicas e metodologias próprias. A grande disparidade de técnicas e metodologias é um dos principais desafios na pesquisa da relação entre cidade e saúde.

Como a história tem mostrado, as cidades têm contribuído, e ainda contribuem, para os diferentes resultados em saúde. Em muitos casos, os níveis de desenvolvimento de um país e de uma cidade são avaliados tendo em conta indicadores de mortalidade. Existem vários indicadores internacionais criados para avaliar o nível da qualidade de vida nas principais cidades do mundo assentes em resultados de saúde. A complexidade do conceito de saúde e bem-estar individual exigem avaliações complexas sobre de que forma as nossas cidades podem contribuir para a saúde e bem-estar individual. As características das nossas cidades influenciam os estilos de vida dos seus habitantes. São esses estilos de vida que influenciam os resultados em saúde. Desta forma, compreender que características do ambiente construído influenciam o estilo de vida individual, e de que forma, é fundamental se pretendermos mudar os resultados em saúde.

3.3 A saúde e a cidade

Os diferentes tipos de mortalidade, como a mortalidade infantil ou materna, têm sido utilizados para descrever o estado de saúde dos países ao longo dos anos. A OMS tem procurado reduzir estas taxas de mortalidade, sobretudo nos países em desenvolvimento, onde aspetos como infraestruturas sanitárias e acesso à água potável têm um forte impacto nas taxas de mortalidade, nomeadamente, nas taxas de mortalidade infantil (Santana, 2014).

Nos países desenvolvidos as diferentes taxas de mortalidade também são usadas para avaliar o de desenvolvimento do país. Porém, as infraestruturas mínimas nos países desenvolvidos estão garantidas na maior parte dos casos, levando a reduzidas taxas de mortalidade relacionadas com a falta desta infraestrutura. No entanto, o contexto dos países desenvolvidos e das sociedades modernas tem levado ao surgimento de outro tipo de mortalidade ou morbilidade. De facto, aspetos como o acesso à água potável ou a existência de infraestruturas sanitárias já existem na quase totalidade deste grupo de países. Nestes locais, é importante avaliar as taxas de mortalidade relacionadas com a sociedade moderna, como as doenças não comunicáveis ou a saúde mental. Nas cidades modernas, os riscos para a saúde estão relacionados com os estilos de vida, nomeadamente, com o consumo de tabaco e álcool, a falta de atividade física com impacto nos níveis de obesidade, ou a morte causada por acidentes rodoviários (Santana, 2015).

A mortalidade por doenças não transmissíveis, como doenças cardiovasculares, cancro e doenças respiratórias crónicas, são a principal causa de morte e representam 74% de mortes ocorridas em todo o mundo. As mortes por doenças não transmissíveis aumentarem em mais de 20 países de baixo e médio rendimento. As taxas incidência de diabetes e obesidade estão a aumentar, inclusive, 54 países tiveram resultados piores do que em 2020, e registaram-se grandes declínios nas campanhas de sensibilização para a atividade física. As doenças não transmissíveis continuam a ser um desafio importante para a saúde pública em todos os países (WHO, 2022).

Tendo isto em mente, a OMS define que, para promover a saúde, é importante trabalhar para além da ausência de doenças, promovendo o bem-estar da população. As taxas de mortalidade diminuíram na maioria dos países desenvolvidos, mas a prevalência de vários tipos de doenças está a aumentar, reduzindo a qualidade de vida e aumentando os custos de saúde (Yu et al., 2017).

As doenças não transmissíveis são de longa duração e, geralmente, de progressão lenta. Os quatro principais tipos de doenças não transmissíveis são doenças cardiovasculares (como ataques cardíacos e AVC), cancros, doenças respiratórias crónicas (como a doença pulmonar obstrutiva crónica e a asma) e diabetes (WHO, n.d.).

No caso da diabetes, a OMS atribui o crescimento da mesma ao envelhecimento da população, à obesidade, às dietas pouco saudáveis e estilos de vida sedentários, relacionados com a urbanização e industrialização (McKinlay & Marceau, 2000). O ambiente construído pode criar um contexto social e físico favorável a estilos de vida saudáveis, sendo um aspeto fundamental na prevenção da diabetes de tipo 2 (WHO, 2016). O relatório global da OMS sobre a diabetes sugere que nenhuma política ou intervenção única pode assegurar a criação de um contexto social e físico de apoio para estilos de vida saudáveis. A criação de um ambiente saudável requer uma abordagem intersectorial, incluindo todos os sectores, para considerar o impacto na saúde em domínios como a agricultura, as finanças, os transportes, a educação, e o planeamento urbano (WHO, 2016).

3.4 O conceito de caminhabilidade

O conceito de caminhabilidade (tradução de "*walkability*", definição adotada nesta tese) tem sido amplamente usado e investigado nos últimos anos em diferentes áreas do conhecimento. Na verdade, o termo "*walkabilitiy*" é dos mais frequentes nas palavras-chave em vários artigos e, numa revisão da literatura, 53% provém das áreas de saúde pública, ambiental e ocupacional (H. Wang & Yang, 2019). O conceito de caminhabilidade refere-se à forma como o ambiente construído é propício à caminhada e pode ser usado para prever níveis de atividade física e viagens ativas (Frank et al., 2006; Sallis, Frank, Saelens, & Kraft, 2004). A definição de caminhabilidade pode ser descrita como um ambiente construído que encoraja as pessoas a caminhar (H. Wang & Yang, 2019). Ainda assim, não existe uma definição consensual para o conceito de caminhabilidade, nem para as metodologias e indicadores usados na sua medição (De Vos et al., 2023; Forsyth, 2015; Saelens & Handy, 2008; H. Wang & Yang, 2019).

Na base do conceito de caminhabilidade está a capacidade do ambiente construído em permitir as deslocações pedonais, daí a palavra caminhabilidade: a habilidade/capacidade de andar (Cambra, 2012; Forsyth & Southworth, 2008). No entanto, as deslocações pedonais são mais complexas do que os modos motorizados pelo que, para além das condições de infraestrutura, que justificam a capacidade de um determinado território tem em promover deslocações em modos motorizados, no caso da caminhabilidade a questão da atratividade dos espaços também é determinante. A atratividade está relacionada com a perceção que os indivíduos têm do ambiente construído, que influencia em si mesma a escolha do modo pedonal (Handy & Clifton, 2001; Krambeck, 2006; Krizek, 2010; Mantri, 2008).

Segundo a *Wikipedia*, e não havendo uma melhor definição formal e consensual sobre o conceito, *"Walkability is a term for planning concepts best understood by the mixed-use of amenities in high-density neighbourhoods where people can access said amenities by foot. It is based on the idea that urban spaces should be more than just transport corridors designed for maximum vehicle throughput. Instead, it should be relatively complete liveable spaces that serve a variety of uses, users, and transportation modes and reduce the need for cars for travel." ."*

Tirando partido das novas ferramentas de inteligência artificial que utilizam a informação disponível online é possível obter uma definição bastante completa:

Walkability refers to the extent to which an area or neighborhood is designed and planned to facilitate safe and convenient walking. Walkable neighborhoods typically have a range of amenities, such as sidewalks, crosswalks, traffic calming measures, and destinations within a reasonable walking distance, which make it easier and more pleasant to walk for transportation, exercise, or leisure.

The concept of walkability has gained significant attention in recent years as a means of promoting physical activity, reducing traffic congestion, and improving public health. Researchers have identified several factors that contribute to walkability, including the presence of well-maintained sidewalks, crosswalks and pedestrian signals, street connectivity, access to public transportation, the presence of commercial and recreational destinations within walking distance, and low levels of crime and perceived safety (ChatGtp 2023).

Ambas as descrições do conceito de caminhabilidade dão uma visão genérica e abrangente do que é a caminhabilidade. No entanto, a forma de medição e os indicadores utilizados dependem da área do conhecimento, bem como da definição do que se pretende avaliar. Na vertente do geógrafo ou do urbanista, a visão terá uma perspetiva mais estratégica, relacionada com a localização e a distribuição das diferentes atividades e equipamentos no território, usando informação socioeconómica e demográfica tratada em ferramentas de análise espacial para suportar a estratégia definida. Por outro lado, a perspetiva do arquiteto terá um objetivo mais próximo do desenho das infraestruturas onde se localizam essas atividades e equipamentos, neste caso, a representação gráfica e modelação tridimensional serão as ferramentas mais utilizadas para se poder descrever o impacto da caminhabilidade. Finalmente, na perspetiva dos profissionais de saúde, a preocupação estará relacionada com os aspetos dos resultados da saúde dos indivíduos, medições biológicas e psicológicas constituirão os resultados a analisar em termos de alterações. Como fica claro, as diferentes perspetivas e abordagens exigem metodologias específicas, usando diferentes fontes e tipos de dados, o que torna complexa a sua integração.

Por outro lado, o contexto geográfico também conduz a metodologias e abordagens diferentes. O contexto norte-americano tem sido fértil na investigação sobre o conceito de caminhabilidade. Desde logo, pelo movimento dirigido por Jane Jacobs e descrito no seu livro *The Death and Life of Great American Cities* (Jacobs, 1963). Este movimento surge como crítica e oposição ao planeamento moderno centrado na promoção da deslocação automóvel, o que levou aos grandes subúrbios americanos de baixa densidade classificados como *urban sprawl*. Esse modelo de planeamento foi exportado para o resto do mundo, levando com ele os vários problemas associados. O resultado do planeamento focado no automóvel leva a aglomerados urbanos monofuncionais, onde as deslocações são maioritariamente motorizadas, conduzindo ao isolamento social de quem não tem acesso automóvel e à falta de acesso a equipamentos e funções apenas alcançáveis através do automóvel. A maior utilização do automóvel resulta num aumento dos níveis de poluição, com impacto na saúde da população, mas também a uma redução dos níveis de atividade física, que, consequentemente, levam ao aumento da obesidade e das doenças associadas. Por outro lado, o maior número de veículos e deslocações motorizadas traduz-se no aumento da sinistralidade automóvel (Frumkin et al., 2004).

De facto, o campo que mais tem explorado o conceito da caminhabilidade é o da área da saúde (Coffee, Howard, Paquet, Hugo, & Daniel, 2013; Sarkar, Webster, & Gallacher, 2018; Tomey, Diez Roux, Clarke, & Seeman, 2013; Van Cauwenberg, Van Holle, De Bourdeaudhuij, Van Dyck, & Deforche, 2016). Caminhar é uma das atividades físicas mais completas, sendo recorrente a recomendação pelos médicos de 30 minutos de caminhada como uma forma de atividade física. É uma atividade que não exige nenhuma ferramenta ou capacidade especial, porém, é necessário que o ambiente o permita fazer em segurança e conforto.

Estudos mostram que as características do ambiente construído exercem uma influência positiva sobre a saúde das populações urbanas, e, em consequência, conduzem a uma perceção positiva sobre as características do ambiente contruído (R. Wang et al., 2019). De uma forma geral, a qualidade do ambiente construído tem um impacto na escolha do modo de transporte, em particular, as deslocações a pé e de transporte público, que afetam os níveis de atividade física e, por conseguinte, a saúde dos cidadãos. De facto, nas últimas décadas foi realizada extensa investigação para compreender a relação entre o ambiente construído e a mobilidade (Ewing & Cervero, 2010a; Frank, Giles-Corti, & Ewing, 2016). Uma forma de organizar as características do ambiente construído que influenciam a mobilidade foi proposta por Cervero e Kockelman (1997) sob três aspetos principais: densidade, diversidade e *design*, designados por 3Ds. Mais tarde, os 3Ds foram expandidos para 5D para incluir a acessibilidade do destino e a distância ao transporte público (Ewing & Cervero, 2010a), e depois para 7D, para incluir a gestão da procura (*Demand management*) e a demografia. A gestão da procura diz respeito à oferta e ao custo do estacionamento, e a demografia é utilizada como um aspeto de controlo nos estudos de viagens (Ewing & Cervero, 2010a). Os meios para medir a maioria destas dimensões são simples e consensuais (densidade, diversidade, acessibilidade ao destino, distância a percorrer e demografia). Contudo, a dimensão de *design* é mais subjetiva e não consensual (Ameli, Hamidi, Garfinkel-Castro, & Ewing, 2015).

De facto, a relação entre o ambiente construído e mobilidade e, em particular, as deslocações pedonais, é mais complexa do que os modos motorizados. Na deslocações pedonais, mais dos que as componentes físicas e diretamente mensuráveis, existe também a questão da perceção individual dessas qualidades e da sua atratividade, que é subjetiva e varia de indivíduo para indivíduo (Hillnhütter, 2022; Stefansdottir, 2018). A Figura 8 explica o quadro conceptual relacionado com a complexidade da relação entre o ambiente construído e o comportamento de caminhar.

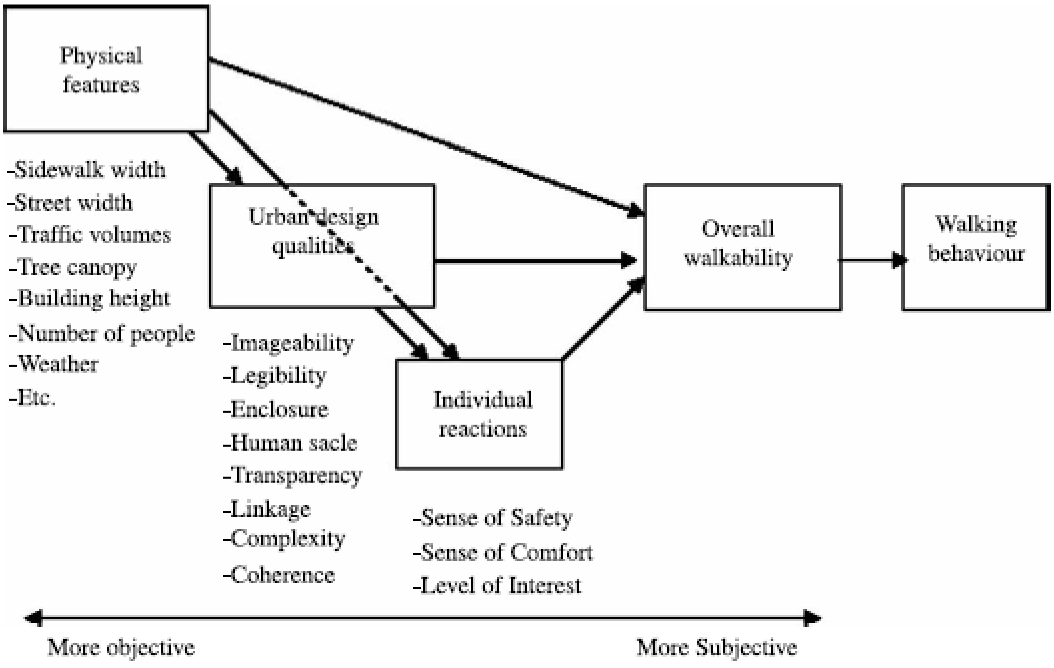


Figura 8 - Modelo conceptual de Ewing and Handy (Ewing & Handy, 2009)

Têm sido utilizadas várias abordagens que consideram a complexidade associada à medição dos aspetos do ambiente construído que influenciam as deslocações pedonais (Cerin et al., 2013; Vale, Saraiva, & Pereira, 2016). Uma das mais frequentes é a criação de índices de caminhabilidade que procuram medir indicadores para as várias dimensões, identificadas através de medidas objetivas com vista a criar um *score* global da caminhabilidade. Estas partem de indicadores de medição mais objetiva, nomeadamente, através de ferramentas de sistema de informação geográfica SIG.

Uma outra forma de medir a caminhabilidade é através de auditorias urbanas por auditores formados para avaliar as qualidades do desenho urbano (Adu-Brimpong et al., 2017; Dannenberg, Cramer, & Gibson, 2005; Millstein et al., 2013; Moudon & Lee, 2003). Contudo, e mesmo com uma formação específica para este fim, a qualidade do desenho permanece subjetiva e varia mesmo entre arquitetos. Face à complexidade da medição das qualidades do ambiente construído e do seu impacto nas perceções individuais, Ewing & Clemente (2013) apresentam cinco conceitos operacionais para representar a qualidade do ambiente construído da perspetiva do peão, que são: imaginabilidade (*imageability*), enclausuramento (*enclosure*), escala humana, transparência e complexidade. Estes conceitos são apoiados por uma forte base teórica, onde se inclui o trabalho de Kevin Lynch no seu livro "A imagem da cidade" (Lynch, 1960), mas também o proposto no livro "A Morte e a Vida das Grandes Cidades Americanas" de Jane Jacobs (1963). Estes cinco conceitos têm sido amplamente utilizados e mostram uma forte correlação com a quantidade de peões em vários contextos (Ameli et al., 2015). Esses conceitos têm sido utilizados para analisar e projetar ambientes urbanos de forma a criar espaços mais legíveis, agradáveis e orientados para as necessidades das pessoas. A imaginabilidade (*Imageability*) corresponde à capacidade de um ambiente ser facilmente recordado pelas pessoas. Um lugar com alta imaginabilidade é inconfundível e possui características visuais únicas e marcantes, o que facilita sua identificação e orientação dos utilizadores. No caso do enclausuramento (*Enclosure*), este descreve a capacidade de o espaço envolver o utilizador. Ambientes com altos níveis de enclausuramento fornecem uma sensação de proteção e segurança, geralmente caracterizada por espaços circunscritos, como ruas estreitas com edifícios altos e vegetação densa. Já a escala Humana (*Human Scale*) refere-se à proximidade das dimensões físicas de um ambiente com as proporções do corpo humano. Ambientes à escala humana são projetados tendo em consideração a perceção e a interação das pessoas, criando espaços confortáveis para os utilizadores. No caso da transparência, esta identifica a capacidade de perceber e compreender o ambiente circundante. A transparência está relacionada com a visibilidade e com a clareza das conexões visuais entre diferentes partes do ambiente. Locais com alta transparência permitem que as pessoas tenham uma compreensão clara do espaço, melhorando a navegação e a orientação. Finalmente, a complexidade avalia a riqueza e diversidade dos elementos presentes no ambiente construído. A complexidade pode ser entendida como a variedade de estímulos sensoriais, elementos visuais, e informações disponíveis. Ambientes complexos oferecem uma experiência mais interessante e estimulante, aumentando a perceção e a interação das pessoas com o espaço (Lynch, 1960).

Seguindo os conceitos propostos por Lynch e operacionalizados por Ewing e Clemente, surge na literatura uma outra forma de organizar as qualidades de design urbano ligadas ao caminhar com base nas necessidades dos peões, neste caso, organizando-se em cinco dimensões, os designados “cinco C’s”:

- **Conectividade**, que identifica as lacunas na rede pedonal;
- **Conveniência**, que descreve a praticidade de caminhar através da rede pedonal, que é influenciada por aspetos como a duração dos semáforos nas passadeiras;
- **Conforto,** que reflete a qualidade da rede na experiência de caminhar ao acomodar as diferenças das capacidades e competências dos utilizadores;
- **Convivialidade,** que descreve o prazer dos peões ao caminharem, em termos de interações com outras pessoas, edifícios e ambiente natural;
- **Conspicuidade**, que define a capacidade da rua e do espaço público para atrair peões, e que está relacionada com a legibilidade espacial, disponibilidade de sinalização, complexidade e coerência (Gardner, Johnson, Buchan, & Pharoah, 1996; Moura et al., 2017).

Os autores Moura et al. (2017), sugerem a introdução de mais dois C's, a **coexistência**, que descreve a segurança do tráfego pedonal e o impacto do tráfego no espaço público, e o **compromisso**, que considera a promoção de políticas amigas dos peões pelas autoridades locais e o compromisso do indivíduo na defesa do espaço público.

A medição das qualidades do desenho urbano são mais exigente em termos de recursos, uma vez que exigem auditores treinados para fazer a avaliação dessas qualidades, bem como uma maior disponibilidade dos participantes desses estudos que acabam por ter um maior contacto e profundidade, como entrevistas ou *focus group* (South et al., 2017).

Entre as duas formas de classificar as características do ambiente construído, a abordagem dos *Ds* foi mais amplamente aceite e utilizada em mais de 200 estudos (Ameli et al., 2015). Ainda assim, ambas as classificações apoiam a ideia de que as características do *design* do ambiente construído influenciam as perceções do indivíduo, afetando a escolha dos modos de transporte, em particular, no que respeita aos modos ativos.

Como referido, um constrangimento importante na medição das qualidades do ambiente construído é a quantidade de recursos necessários. Assim, vários autores sugerem abordagens alternativas para medir estas qualidades, numa tentativa de reduzir estes requisitos. Um exemplo é utilizar imagens do *google street view* como um substituto para auditorias urbanas, o que tem tido bons resultados (Griew et al., 2013; Mooney et al., 2016; Rundle, Bader, Richards, Neckerman, & Teitler, 2011; Yin, Cheng, Wang, & Shao, 2015; Yin & Wang, 2016). Outro exemplo baseia-se na tradução dos conceitos identificados por Ewing (imaginabilidade, enclausuramento, escala humana, transparência e complexidade) para indicadores mensuráveis através de métodos automatizados, designadamente, usando sistemas de informação geográfica para a criação e cálculo desses indicadores (Ewing & Handy, 2009; Purciel et al., 2009).

As ferramentas e metodologias desenvolvidas nessa investigação têm sido utilizadas para explicar o número de peões no espaço público, concluindo que ambientes mais favoráveis para as deslocações a pé em termos de infraestruturas e qualidades estéticas aumentam o número de pessoas andar a pé nesses locais. Sabendo os benefícios associados à atividade de andar a pé, muito do conhecimento e ferramentas foram aplicadas em estudos que explicam os níveis de saúde da população, sendo os mais frequentes os relacionados com os níveis de obesidade (Glanz et al., 2016; Sallis et al., 2009). Esses estudos concluem que os espaços mais caminháveis contribuem com o aumento das deslocações a pé, o que se traduz num aumento da atividade física e, consequentemente, numa redução dos níveis de obesidade.

3.5 O contributo de espaços caminháveis para a saúde.

O conceito de caminhabilidade tem sido aplicado em vários campos, como o planeamento urbano, os transportes e a saúde pública. São inegáveis os impactos de um "espaço mais favorável ao caminhar" para o bem-estar social, sanitário e económico de uma sociedade (Frank et al., 2006). As características relacionadas com uma maior caminhabilidade têm demonstrado uma relação com o aumento da atividade física com consequências para os níveis de obesidade. As deslocações a pé e de bicicleta aumentam em bairros onde as condições para andar são melhores em comparação com bairros onde estas condições são piores (Frank et al., 2010; Sallis et al., 2009).

A promoção de espaços mais caminháveis possibilita um aumento dos níveis de atividade física, importante para reduzir os níveis de obesidade que atingiram uma proporção epidémica em quase todos os países desenvolvidos. O aumento da obesidade é uma consequência de estilos de vida fisicamente inativos. Por outro lado, espaços onde o carro tem maior prevalência aumentam os níveis de poluição do ar, com impacto no aumento da prevalência de doenças respiratórias, mas também o aumento do risco de acidentes rodoviários. De acordo com a Organização Mundial da Saúde (OMS), estima-se que em 2020 a poluição do ar foi responsável por aproximadamente sete milhões de mortes prematuras em todo o mundo. Essas mortes estão relacionadas a doenças cardiovasculares, doenças respiratórias crónicas, cancro do pulmão, e outros problemas de saúde, agravados pela exposição a altos níveis de poluição atmosférica.

As cidades possuem um efeito direto na saúde, por exemplo, através do contacto com a poluição e com o risco de acidentes rodoviários, mas também assumem um impacto indireto através do contributo para as alterações dos hábitos e estilos de vida que podem conduzir a uma melhoria do estado e saúde e bem-estar. Estes estilos de vida têm impacto na saúde dos indivíduos, aumentando os seus riscos de doenças e morte prematura, e aumentando também os custos dos cuidados de saúde (Jarrett et al., 2012; Santana et al., 2009). Muitos estudos analisam a relação entre a capacidade de caminhar e o estado de saúde dos residentes. Os resultados destes estudos mostram uma relação inegável, mas não clarificam quais são as contribuições de cada um dos indicadores (Coffee et al., 2013; Müller-Riemenschneider et al., 2013; Sallis et al., 2009). Além disso, a relação de causalidade permanece pouco explícita.

Os vários modelos ecológicos têm proposto várias explicações para a relação entre o ambiente construído e a saúde e bem-estar dos seus indivíduos. A literatura tem mostrado relações complexas entre os vários fatores, sugerindo relações de moderação e mediação entre as variáveis consideradas, nomeadamente, o efeito indireto do ambiente construído nos estilos de vida mais saudáveis, que, por sua vez, conduzem a uma melhoria do estado de saúde. A presente investigação desenvolve os modelos propostos pela literatura, com as necessárias alterações para o contexto português, de forma a clarificar essas relações e contribuir para o seu conhecimento.

3.6 A caminhabilidade e o estatuto socioeconómico.

As características socioeconómicas do indivíduo e do país onde vive influenciam muito os resultados em saúde. A falta de infraestruturas de saúde e equipamentos condiciona estilos de vida mais saudáveis. Por outro lado, caso existam essas infraestruturas, mas o indivíduo não tenha capacidade económica ou física para lhes aceder, os seus níveis de saúde e bem-estar também ficam comprometidos. O estatuto socioeconómico (SES) de um indivíduo tem uma importância determinante nos vários aspetos da vida individual. Os dados mostram que indivíduos de baixo SES têm condições de saúde precárias, quando comparados com indivíduos de melhores estratos sociais. (Adams, Cavill, & Sherar, 2017; Dimitrovová, Costa, Santana, & Perelman, 2017; Jiao et al., 2016). As condições socioeconómicas são importantes para o acesso a diferentes equipamentos de lazer, de saúde, de mobilidade, e que têm impacto na sustentabilidade e bem-estar da população.

As cidades concentram a maior parte da população, o que cria desafios na sua gestão e faz delas um elemento crucial para um desenvolvimento sustentável e equitativo (da Cruz et al., 2020; UN-Habitat, 2016). O crescimento da população aumentará a procura de atividades e equipamentos, o que, por sua vez, levará ao aumento dos preços das casas, no caso de não existir possibilidade de aumentar a capacidade de construção. O centro da cidade é, geralmente, a área mais desejada para se viver: tem melhor acesso aos transportes públicos e um ambiente construído que permite andar a pé, reduzindo a necessidade de viagens motorizadas individuais. No entanto, os preços elevados dos imóveis reduzem a diversidade social, uma vez que apenas uma pequena proporção da população tem capacidade económica para viver nesses locais (Padeiro, Louro, & da Costa, 2019). Isto pode levar a uma situação em que os indivíduos mais desfavorecidos são impelidos para as zonas de pior acessibilidade e com menos equipamentos. Estas pessoas têm menos opções de mobilidade, custos de transporte e tempo de deslocação mais elevados, e podem mesmo ser excluídas de exercer certas atividades pela sua menor mobilidade e acessibilidade (Currie & Delbosc, 2010; Delbosc & Currie, 2011b).

Neste contexto, vários estudos exploraram a relação entre caminhabilidade e o estatuto socioeconómico, com resultados contraditórios (King & Clarke, 2015; Su et al., 2019; Thornton et al., 2016). A maioria dos estudos examinou os contextos norte-americano e australiano, onde a distribuição espacial dos grupos socioeconómicos é mais marcada (Cowie et al., 2016; King & Clarke, 2015; Thornton et al., 2016). Apenas alguns estudos foram realizados no contexto europeu (Gullón et al., 2017). Na Europa, a distribuição da população no território foi influenciada por diferentes eventos e padrões (Munoz, 2003), criando uma distribuição da população de diferentes extratos socioeconómicos ,que é distinta entre os vários países. No caso de Portugal, a Área Metropolitana de Lisboa (AML) é ocupada por diferentes grupos socioeconómicos em ambientes com diferentes níveis de acessibilidade (Garcia, Macário, Menezes, & Loureiro, 2018; Santana, Nogueira, & Santos, 2007). Contudo, pouco se sabe sobre a distribuição da caminhabilidade na AML.

Ambientes construídos com uma melhor acessibilidade e melhores condições de caminhabilidade possuem um valor mais elevado, excluindo as populações mais desfavorecidas, renegadas para localizações mais limítrofes e com piores condições de acessibilidade, criando desigualdade sociais. No entanto, um ambiente que apoie a utilização de modos de transporte ativo pode reduzir as desigualdades socio espaciais (Badland et al., 2014; Giles-Corti et al., 2016). Além disso, um ambiente que promova modos ativos pode beneficiar a saúde, a gestão do tráfego, a qualidade do ar e a economia (Giles-Corti et al., 2016). A literatura mostra que viver em ambientes pouco caminháveis e com baixos níveis de acessibilidade tem consequências negativas para a saúde e segurança, aumentando também o risco de obesidade para a população que vive nestes ambientes (Santana et al., 2009). Além disso, os benefícios das viagens ativas são especialmente importantes para as populações desfavorecidas e vulneráveis, uma vez que estas têm mais dificuldades de acesso a outros meios de transporte, usualmente mais caros (Adkins, Makarewicz, Scanze, Ingram, & Luhr, 2017). De facto, a acessibilidade é outro aspeto importante para o bem-estar individual (Delbosc & Currie, 2011b) e tem sido considerada como estando intimamente relacionada com a desigualdade em muitas cidades, incluindo Lisboa (Garcia et al., 2018; Page, Langford, & Higgs, 2018).

Na Área Metropolitana de Lisboa , estudos anteriores revelaram que indivíduos de baixo nível socioeconómico fazem menos viagens não essenciais. Isto é um resultado do elevado nível de dependência do automóvel, uma vez que muitas oportunidades só são acessíveis por este modo de transporte (Pritchard, Moura, Silva, & Martinez, 2014). Adicionalmente, o elevado nível de dependência do automóvel reflete a falta de integração dos usos do solo e do sistema de transporte. Deste modo, as características do ambiente construído suportam determinadas opções de mobilidade que acabam por estar relacionadas com as características socioeconómicas da população (Adkins et al., 2017; Ewing & Cervero, 2010b). Em termos gerais, indivíduos de grupos com estatuto socioeconómico mais elevado podem viver em locais com melhor acessibilidade a diferentes atividades e equipamento, e, ao mesmo tempo, ter capacidade de utilizar meios de transporte mais caros, nomeadamente, o automóvel. Ainda assim, não parece haver qualquer relação entre níveis de acesso a atividades e equipamentos e grupos socioeconómicos. Por outro lado, Koschinsky and Talen (2015) revelam que em muitas áreas suburbanas, com menor caminhabilidade, residem indivíduos de rendimentos mais elevados, e que as áreas urbanas com populações de rendimentos mais baixos em zonas históricas têm, frequentemente, melhor acessibilidade.

Um ambiente urbano sustentável deve incluir um sistema de transporte acessível e económico que permita aos indivíduos chegar a destinos importantes por vários modos. Estes modos implicam custos com diferentes efeitos em diferentes grupos socioeconómicos (Delbosc & Currie, 2011a; Vale, 2020). Em particular, a distribuição não equitativa de ambientes pedonais pode aumentar os custos de transporte para a população mais desfavorecida. Assim, durante a última década, os especialistas em transportes prestaram maior atenção às questões de equidade de acesso, tendo em conta as necessidades dos diferentes grupos socioeconómicos. Isto é, as políticas de mobilidade devem ser equitativas em vez de igualitárias, fornecendo alternativas e opções ajustadas às condições e limitações dos diferentes grupos socioeconómicos, distribuídos por ambientes construídos com diferentes qualidades e opções de mobilidade (Adkins et al., 2017; Bereitschaft, 2017; Carleton & Porter, 2018; Delbosc & Currie, 2011a).

Embora os modos privados e motorizados aumentem a acessibilidade e melhorem a mobilidade individual, estão menos disponíveis para grupos mais pobres e mais desfavorecidos. A falta de opções de transporte pode ser não só o resultado da exclusão social, mas pode também reforçá-la. Uma deficiente rede de transportes públicos tem um impacto maior nas camadas desfavorecidas da população, uma vez que impede que os indivíduos acedam aos locais de trabalho e educação, limita a participação em atividades sociais e comunitárias e dificulta o acesso aos serviços de saúde (Delbosc & Currie, 2011b). Estes problemas podem ser parcialmente reduzidos através de um desenho caminhável que permita e promova as deslocações a pé, reduzindo a distância que tem de ser percorrida para alcançar atividades importantes. Todavia, embora uma maior caminhabilidade possa melhorar a saúde das populações e aumentar a equidade (Santana et al., 2009), também aumenta os preços dos imóveis (Carmona, Gabrieli, Hickman, Laopoulou, & Livingstone, 2018; Mulley & Tsai, 2013). Por sua vez, valores imobiliários mais elevados tendem a atrair residentes mais ricos e a excluir grupos mais pobres (Büttner, Kinigadner, Ji, Wright, & Wulfhorst, 2018), o que sugere que uma maior caminhabilidade pode estar associada a bairros com residentes de rendimentos elevados.

Estas considerações realçam o impacto que o ambiente construído pode ter na distribuição espacial da população. Em teoria, os locais mais acessíveis são os mais valiosos, e apenas acessíveis a grupos socioeconómicos de maior rendimento (Gullón et al., 2017). Na prática, a distribuição espacial dos lugares mais caminháveis não é igual entre países e cidades, e nem sempre é representativa do estatuto socioeconómico da população local (Gullón et al., 2017).

Em Portugal, a investigação sobre caminhabilidade ainda é reduzida. Foram feitos alguns indicadores para Lisboa em diferentes escalas e considerando diferentes grupos de habitantes, evidenciando uma correlação positiva entre a caminhabilidade estimada e as viagens pendulares feitas a pé. Estes indicadores mostraram também que as intervenções da cidade têm vindo a melhorar as condições de caminhabilidade (Cambra, 2012; Cambra & Moura, 2020; Moura et al., 2017). No entanto, é necessária mais investigação, não só para compreender a aplicabilidade no contexto português, mas também para compreender claramente a relevância dos vários indicadores de ambiente construído para a criação de uma cidade mais saudável. Na investigação da caminhabilidade no contexto português, destaca-se ainda uma tese de mestrado acompanhada pela Câmara de Lisboa, que desenvolveu o potencial pedonal de Lisboa. O potencial pedonal analisa e prevê onde será mais provável que haja um maior fluxo de peões. Para prever este fluxo de peões, o autor utiliza dois componentes: primeiro, a localização de polos de geração de viagens com diferentes níveis de importância, tais como a escola ou os transportes públicos; em segundo lugar, usa a densidade populacional, prevendo mais peões onde a densidade é mais elevada. A investigação demonstrou que estes polos geram mais deslocações pedonais, sendo prioritários no caso de intervenções na cidade para a melhoria da caminhabilidade (Morais, 2013).

Todavia, como se tem descrito, o conceito de saúde é mais complexo do que a ausência de doenças e vai para além de um maior nível de atividade física. As deslocações a pé são importantes e têm sido o objetivo a alcançar em grande parte dos estudos sobre caminhabilidade e saúde. Não obstante, a criação de espaços mais saudáveis deverá ir além da promoção da atividade física, incluindo também a possibilidade de interação social, o acesso a espaços verdes, e o sentimento de segurança. O desafio é criar ferramentas e instrumentos que possibilitem o desenho de cidades com características que promovam as várias dimensões da saúde dos seus habitantes.

3.7 Relação entre a caminhabilidade e a saúde

A relação entre a cidade e a saúde individual evoluiu acompanhado o aumento da complexidade da sociedade e dos seus indivíduos. No início da história, a preocupação era garantir que a cidade não causasse danos à saúde e que permitisse o bom desenvolvimento da sociedade, daí a sua preocupação com os ventos dominantes, a proximidade à água, etc. Na sociedade moderna, e uma vez que são poucas as cidades que surgem de novo, a preocupação é que a cidade crie condições para hábitos e estilos de vida mais saudáveis. De uma forma geral, as cidades já não são um risco para a saúde, mas contribuem para estilos de vida que podem, ou não, ser um risco para a saúde. As exceções são questões interdependentes, relacionadas com a qualidade do ar e a temperatura, que criam ilhas de calor cada vez mais frequentes em cidades mais densas (O’Brien, Ross, & Strachan, 2019; Shi, Ren, Lau, & Ng, 2019). No entanto, o aspeto da qualidade do ar pode ser minimizado alterando-se comportamentos individuais, em particular, modificando padrões de mobilidade com o aumento dos modos ativos e o uso do transporte público (Ballinger, Chowdhury, Crombie, & Owen, 2017; Marshall et al., 2009). Deste modo, a literatura tem demostrado que as características do ambiente construído são fundamentais para o sucesso de medidas de promoção da saúde da população em diferentes setores. Por exemplo, campanhas de promoção de atividade física apresentam maior sucesso se acompanhadas por uma melhoria dos equipamentos e dos espaços verdes (Giles-Corti, 2006; Sallis et al., 2006). Outro exemplo é a questão da alimentação, em que medidas de promoção de hábitos mais saudáveis estarão condenadas ao insucesso se a população não tiver acesso a produtos mais saudáveis, ou até mesmo meios para os adquirir (Paquet et al., 2014). Os modelos ecológicos assentam na premissa de que é necessária uma abordagem holística nos vários níveis e camadas do contexto do indivíduo para haver sucesso nas alterações dos estilos de vida (Sallis et al., 2006).

A relação entre caminhabilidade e saúde surge na premissa de que um espaço que suporta as deslocações a pé aumentará essas mesmas deslocações. A maior parte da literatura sobre caminhabilidade e saúde está relacionada com a questão da atividade física (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Saelens & Handy, 2008) e com o seu impacto na redução dos níveis de obesidade, obtendo-se benefícios relacionados com a incidência de outros tipos de doenças, em particular, as não-transmissíveis (Garfinkel-Castro, Kim, Hamidi, & Ewing, 2017; Lam, Vaartjes, Grobbee, Karssenberg, & Lakerveld, 2021). No entanto, como temos visto, a noção de saúde é complexa e olhar apenas para questão da atividade física pode ser redutor. Por outro lado, a recente pandemia de Covid-19 levantou questões que no início na investigação não eram sequer consideradas. O período de tempo na análise empírica da tese não cobre o período da pandemia, porém, considero importante referir a importância que este evento mundial trouxe à forma como vemos a saúde e como as cidades contribuem para essa visão. De facto, as questões de caminhabilidade para a saúde passaram a ir além da possibilidade de suportar as deslocações a pé, mas para as fazer de forma a garantir a distância de segurança para evitar o contágio. Surgiram, inclusive, análises às características das infraestruturas pedonais de forma a garantir o distanciamento social para conter a disseminação da doença (NACTO, 2020). Surgiram também projetos de alteração do espaço público para garantir o distanciamento social ou formas de suportar deslocações em bicicleta de modo a reduzir a quantidade de pessoas no transporte público. Por outro lado, a situação do Covid-19 foi algo tão disruptivo que ainda é difícil analisar o seu impacto nas alterações na forma de utilização do espaço público. No entanto, a banalização do trabalho remoto trouxe alterações aos padrões de mobilidade e flexibilização dos modos de trabalho, que trarão impactos ao nível de atividade física. Por outro lado, o maior distanciamento social poderá aumentar o risco das doenças mentais, em particular, a depressão.

Retomando o conceito de saúde da WHO, a saúde não é apenas a ausência da doença, mas um sentimento geral de bem-estar. É devido a essa questão de bem-estar que outros autores têm explorado o contributo de espaços mais caminháveis para o bem-estar. O contributo para o bem-estar ou felicidade tem sido explorado através das características do ambiente construído (Kent et al., 2017; Kent & Thompson, 2014; Martin, Goryakin, & Suhrcke, 2014; Toma et al., 2015). Uma das conclusões obtidas é que as características do bairro onde o indivíduo mora funcionam como uma extensão das suas condições individuais. Isto faz com que a perceção que o indivíduo tem sobre o seu bairro influencie a perceção que tem sobre si próprio (Hillnhütter, 2022; Kyttä, Broberg, Haybatollahi, & Schmidt-Thomé, 2016; Stefansdottir, 2018). A perceção das características do ambiente construído tem impacto no valor da propriedade e, consequentemente, na perceção da condição social do indivíduo. Desta forma, as características do ambiente construído não só influenciam os estilos de vida e promovem a atividade física, mas condicionam a perceção que o indivíduo tem si próprio e até daquilo que alcançou na vida, com reflexo na sua casa ou no bairro onde pode morar (Jiao et al., 2016; Stefansdottir, 2018).

Outro aspeto importante da perceção das características do ambiente construído é a perceção de segurança. A questão da perceção é extremamente importante para a questão da caminhabilidade. Neste caso, a questão da perceção é duplamente penosa para a saúde, por um lado, porque reduz os níveis de atividade física em resultado de menos deslocação pedonal e, por outro, porque aumenta o risco de isolamento social e traumas associados ao risco de andar na rua. Este aspeto é particularmente importante se considerarmos a questão no género, pois o risco ou insegurança no espaço público é maior no caso da mulher (Adlakha & Parra, 2020; González-Sánchez et al., 2017; Lubitow, Abelson, & Carpenter, 2020). Neste caso, as ferramentas e indicadores utilizados em grande parte da literatura sobre caminhabilidade e saúde não seriam capazes de medir esta dimensão. As dimensões descritas pelos D's (densidade, diversidade e design), ou até mesmo pelos C's, não cobrem estes aspetos de perceção de segurança. Grande parte da literatura sobre caminhabilidade e saúde está focada na questão da infraestrutura, ou tende a avaliar diferentes aspetos a escalas diferentes sem ter uma visão conjunta das interações entre escalas, características e perceções.

A natural complexidade do indivíduo e as diferente dimensões das nossas cidades tornam compreender de que forma as diferentes dimensões da cidade contribuem para a complexa situação de saúde um grande desafio. Assumindo que a relação causal será praticamente impossível de alcançar, pretendo analisar esta visão conjunta das diferentes dimensões e escalas do ambiente construído para explicar diferentes aspetos da saúde individual, incluindo aspetos mais físicos e biológicos como a doença ou a perceção individual de si próprio e da sua saúde.

4 Dados, medidas e opções metodológicas de investigação

4.1 *Estrutura conceptual*

A presente investigação analisa a contribuição do ambiente construído para um melhor estado de saúde. A complexidade da saúde requer uma avaliação do ambiente construído a diferentes escalas e com diferentes de abordagens. Desta forma, a investigação começa por avaliar as condições de caminhabilidade para a Área Metropolitana de Lisboa (AML). No que diz respeito à saúde, a avaliação começou por olhar para a questão das doenças, neste caso, as admissões hospitalares. À medida que se aumentou o detalhe na avaliação do ambiente construído, utilizaram-se as várias abordagens usando dados de fontes secundárias.

A literatura tem demonstrado que as diferentes escalas do ambiente construído têm diferentes tipos de efeitos sobre a saúde, sugerindo a necessidade de uma abordagem multinível e ecológica (Kanuganti, Sarkar, & Singh, 2016). Desta forma, é necessário integrar diferentes campos de planeamento, saúde e ciências sociais para definir um programa bem-sucedido para melhorar a qualidade da saúde.

4.1.1 Escala regional (Freguesias da Área Metropolitana de Lisboa - AML)

A revisão bibliográfica identificou a influência do ambiente construído na saúde através de diferentes escalas. Assim, a tese segue uma visão holística na perspetiva do arquiteto e urbanista, desde a visão estratégia de caráter metropolitano até ao nível do desenho do passeio e do espaço público. A primeira abordagem à realidade portuguesa foi feita para o nível regional, considerando as freguesias dos 18 municípios que formam a Área Metropolitana de Lisboa. os índices de mortalidade e os internamentos hospitalares por diferentes causas constituíram as variáveis dependentes da análise. Este é o momento em que os indicadores de caminhabilidade mais utilizados e identificados na literatura foram testados para explicar as variáveis dependentes em saúde.

4.1.2 Escala Regional (Census)

A abordagem seguinte, ainda à escala regional, usa informação mais detalhada à escala da subsecção estatística, explorando a relação entre as condições socioeconómicas e as qualidades de caminhabilidade. Esta abordagem surgiu no seguimento dos resultados das primeiras análises que indicaram uma relação entre a saúde, as condições socioeconómicas, e as qualidades do ambiente construído.

Esta fase resultará num trabalho que relacionará e concluirá a distribuição da boa caminhabilidade e do estatuto SES para a AML.

4.1.3 Escala da rua

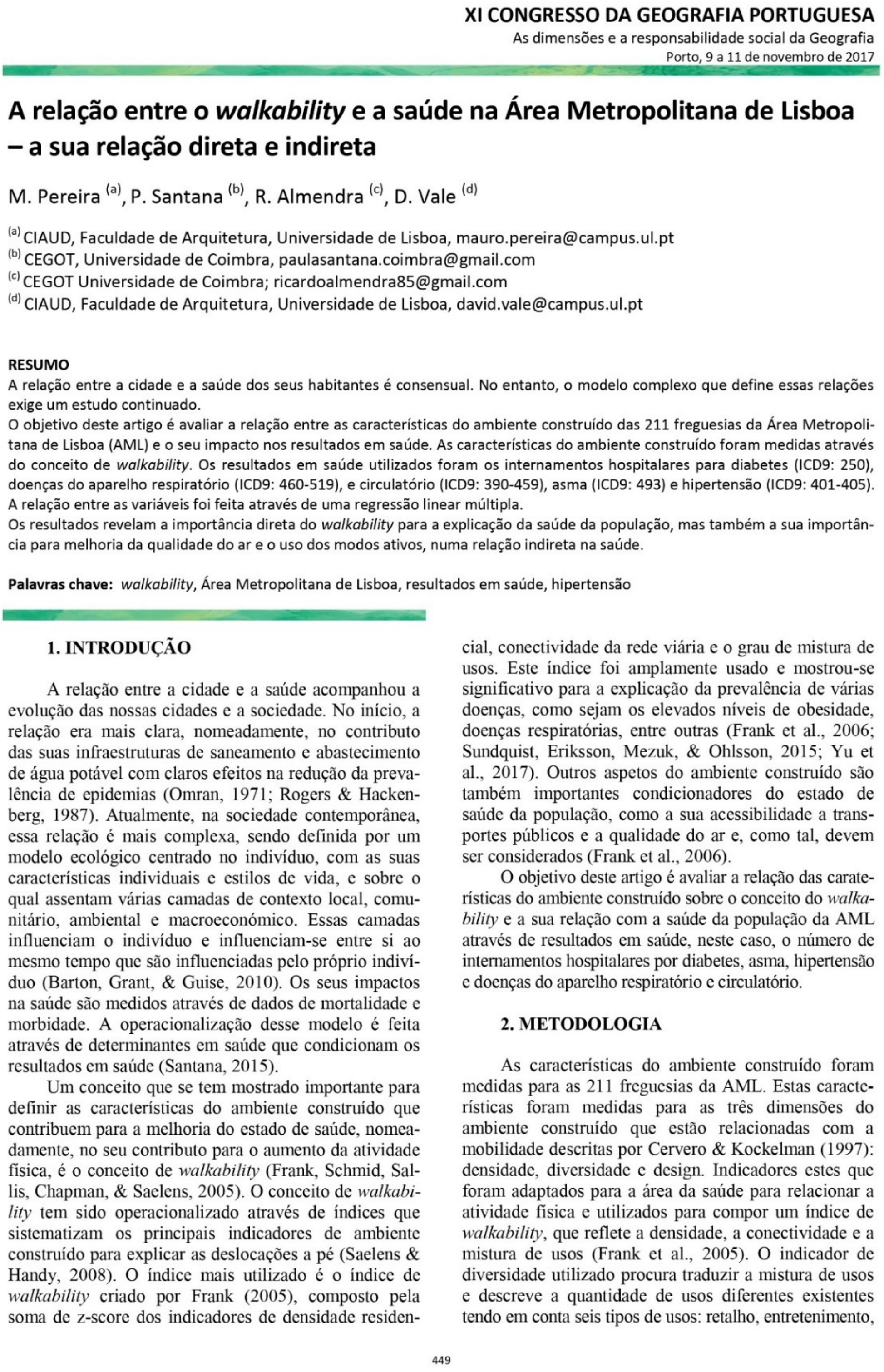
O último nível de análise diz respeito à escala mais detalhada e mais próxima de influenciar a perceção física e emocional do individuo. Ao nível da rua são avaliadas as dimensões descritas pela literatura dos C's, mas, principalmente, analisa-se a literatura relativa ao impacto da perceção das qualidades do ambiente construído para o indivíduo. As qualidades do desenho da rua são descritas como relacionadas com a sua imaginabilidade (*imageability*), enclausuramento (*enclosure*), escala humana, transparência, e complexidade, mas também incluem a perceção de segurança. Relativamente este último nível, foi elaborada uma representação mais detalhada do desenho urbano recorrendo a cartografia 1:10 000 para identificação e cálculo de indicadores urbanos. Foi também incluída a utilização de imagens de rua para identificação de elementos do espaço público, importantes para a perceção de segurança que abrange a identificação de semáforos, mobiliário urbano, montras, sistemas de vigilância, etc.

A esta escala existe um aumento do nível de detalhe com a avaliação das características do ambiente construído à escala da rua. No entanto, inclui as várias dimensões anteriores de forma a avaliar o contributo relativo destas várias escalas para a saúde e bem-estar individual.

5 Resultados da investigação

(página em branco propositadamente)

5.1 I. A relação entre o walkability e a saúde na Área Metropolitana de Lisboa – a sua relação direta e indireta



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As dimensões e a responsabilidade social da Geografia
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A relação entre o *walkability* e a saúde na Área Metropolitana de Lisboa – a sua relação direta e indireta

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RESUMO

A relação entre a cidade e a saúde dos seus habitantes é consensual. No entanto, o modelo complexo que define essas relações exige um estudo continuado.

O objetivo deste artigo é avaliar a relação entre as características do ambiente construído das 211 freguesias da Área Metropolitana de Lisboa (AML) e o seu impacto nos resultados em saúde. As características do ambiente construído foram medidas através do conceito de *walkability*. Os resultados em saúde utilizados foram os internamentos hospitalares para diabetes (ICD9: 250), doenças do aparelho respiratório (ICD9: 460-519), e circulatório (ICD9: 390-459), asma (ICD9: 493) e hipertensão (ICD9: 401-405). A relação entre as variáveis foi feita através de uma regressão linear múltipla.

Os resultados revelam a importância direta do *walkability* para a explicação da saúde da população, mas também a sua importância para melhoria da qualidade do ar e o uso dos modos ativos, numa relação indireta na saúde.

Palavras chave: *walkability*, Área Metropolitana de Lisboa, resultados em saúde, hipertensão

1. INTRODUÇÃO

A relação entre a cidade e a saúde acompanhou a evolução das nossas cidades e a sociedade. No início, a relação era mais clara, nomeadamente, no contributo das suas infraestruturas de saneamento e abastecimento de água potável com claros efeitos na redução da prevalência de epidemias (Omran, 1971; Rogers & Hackenberg, 1987). Atualmente, na sociedade contemporânea, essa relação é mais complexa, sendo definida por um modelo ecológico centrado no indivíduo, com as suas características individuais e estilos de vida, e sobre o qual assentam várias camadas de contexto local, comunitário, ambiental e macroeconómico. Essas camadas influenciam o indivíduo e influenciam-se entre si ao mesmo tempo que são influenciadas pelo próprio indivíduo (Barton, Grant, & Guise, 2010). Os seus impactos na saúde são medidos através de dados de mortalidade e morbidade. A operacionalização desse modelo é feita através de determinantes em saúde que condicionam os resultados em saúde (Santana, 2015).

Um conceito que se tem mostrado importante para definir as características do ambiente construído que contribuem para a melhoria do estado de saúde, nomeadamente, no seu contributo para o aumento da atividade física, é o conceito de *walkability* (Frank, Schmid, Sallis, Chapman, & Saelens, 2005). O conceito de *walkability* tem sido operacionalizado através de índices que sistematizam os principais indicadores de ambiente construído para explicar as deslocações a pé (Saelens & Handy, 2008). O índice mais utilizado é o índice de *walkability* criado por Frank (2005), composto pela soma de z-score dos indicadores de densidade residencial, conectividade da rede viária e o grau de mistura de usos. Este índice foi amplamente usado e mostrou-se significativo para a explicação da prevalência de várias doenças, como sejam os elevados níveis de obesidade, doenças respiratórias, entre outras (Frank et al., 2006; Sundquist, Eriksson, Mezuk, & Ohlsson, 2015; Yu et al., 2017). Outros aspetos do ambiente construído são também importantes condicionadores do estado de saúde da população, como a sua acessibilidade a transportes públicos e a qualidade do ar e, como tal, devem ser considerados (Frank et al., 2006).

O objetivo deste artigo é avaliar a relação das caraterísticas do ambiente construído sobre o conceito do *walkability* e a sua relação com a saúde da população da AML através de resultados em saúde, neste caso, o número de internamentos hospitalares por diabetes, asma, hipertensão e doenças do aparelho respiratório e circulatório.

2. METODOLOGIA

As características do ambiente construído foram medidas para as 211 freguesias da AML. Estas características foram medidas para as três dimensões do ambiente construído que estão relacionadas com a mobilidade descritas por Cervero & Kockelman (1997): densidade, diversidade e design. Indicadores estes que foram adaptados para a área da saúde para relacionar a atividade física e utilizados para compor um índice de *walkability*, que reflete a densidade, a conectividade e a mistura de usos (Frank et al., 2005). O indicador de diversidade utilizado procura traduzir a mistura de usos e descreve a quantidade de usos diferentes existentes tendo em conta seis tipos de usos: retalho, entretenimento, alimentação, institucionais, escritórios e recreio. Os dados são provenientes dos pontos de interesse da informação da Navteq. O indicador densidade de nós ilustra a conectividade da rede viária e contabiliza a densidade de nós com mais de três ligações pela área da freguesia - a fonte é a mesma dos POIs. Finalmente, a densidade residencial utiliza os dados do INE para o número de alojamentos ao nível da freguesia.

Os dados socioeconómicos utilizados foram os dos Censos 2011 à freguesia. Com base nesses dados foi criado, ainda, um indicador de privação múltipla composto por Taxa de Desemprego, Taxa de Analfabetismo e Percentagem de Alojamentos Familiares de Residência Habitual sem Retrete, indicadores que revelaram maior capacidade para "sintetizar" a privação material com influência no estado de saúde da população (Loureiro, Costa, Almendra, Freitas, & Santana, 2015). A metodologia utilizada para a construção desse índice foi o método de Carstairs & Morris (1990).

Os resultados em saúde utilizados foram os internamentos hospitalares para diabetes (ICD9: 250), doenças respiratórias (ICD9: 460-519), doenças do aparelho circulatórios (ICD9: 390-459), asma (ICD9: 493) e hipertensão (ICD9: 401-405), dados provenientes da base geral dos Grupos de Diagnósticos Homogéneos (GDH).

Os vários indicadores, assim como os índices criados, foram avaliados sobre a sua significância para a explicação dos vários internamentos por doença através de uma regressão linear múltipla, com estimação dos parâmetros pelo método da máxima verosimilhança implementado no software AMOS. O modelo teórico a explorar relaciona as características do *walkability* para a saúde e considera os aspetos socioeconómicos como variáveis de controlo. A utilização do *software* AMOS através da análise de trajetórias permite identificar efeitos de mediação e moderação expectáveis em algumas das variáveis.

3. RESULTADOS E DISCUSSÃO

A tabela 1 apresenta os vários indicadores ponderados na análise, assim como as principais estatísticas descritivas onde é possível verificar a existência de indicadores que violam os pressupostos de normalidade (Marôco, 2010). Nesse sentido, vários indicadores foram transformados. Na tabela 1 é ainda possível avaliar os resultados na regressão linear múltipla utilizando como variável dependente as vários causas de internamento. Nessa análise estatística é possível concluir que a taxa de internamentos por hipertensão é a variável dependente com maior percentagem de variância explicada (R^2 = 0.390). Por outro lado, os internamentos por doenças do sistema circulatório são o único modelo que possuiu uma variável independente estatisticamente significativa para p<0.001, neste caso, a percentagem de população residente que utiliza transportes públicos e modos ativos diariamente. Tendo como critério o valor mais elevado de R^2, modelos mais complexos foram desenvolvidos para a explicação dos internamentos por hipertensão. Considerando a complexidade associada à explicação da saúde, são expectáveis efeitos de moderação ou mediação entre as variáveis (Ding & Gebel, 2012; Oliver et al., 2015). Assim, um modelo de análise de trajetórias foi criado para avaliar esses efeitos. Na criação nesse modelo foram utilizados os índices privação múltipla e o índice de *walkability*, em resultado da previsível colinearidade com as variáveis que compõem esses índices ilustrado pelos VIF (tabela 1).

Tabela 1 – Estatísticas descritivas e regressão linear múltipla dos indicadores considerados.

		Estatística Descritiva						Regressão linear múltipla									
Indicador	**Descrição**	**Min**	**Max**	**Média**	***Skewness***	***Kurtosis***	**VIF**										
Socio-Economico								p	β	p	β	p	β	p	β	p	β
SES_AFRHSR	Alojamentos familiares de residência habitual sem Existência de retrete (%)	0.00	3.60	0.34	3.36	15.05											
SES_SqAFRHSR	Sqr(Alojamentos familiares de residência habitual sem Existência de retrete)	0.00	1.90	0.48	1.20	2.06	9.26	0.284	0.21	0.140	0.26	0.200	0.25	0.651	0.09	0.041	0.33
SES_ESC	Proporção da população residente com ensino superior completo (%)	4.00	56.49	20.48	1.04	0.49	3.96	0.124	-0.20	0.536	0.07	0.725	-0.04	0.019	-0.29	0.360	-0.10
SES_TA	Taxa de analfabetismo (%)	0.75	13.58	3.89	1.62	4.03	15.98	0.383	0.22	0.528	0.15	0.261	0.29	0.898	0.03	0.002	0.66
SES_TD	Taxa de desemprego (%)	6.54	27.60	12.62	0.91	2.12	9.59	0.751	0.06	0.825	0.04	0.668	0.08	0.540	0.12	0.145	0.24
SES_IPM	Índice de Privação Material 2011	-3.85	10.20	0.00	1.58	4.84	40.35	0.500	-0.27	0.514	-0.24	0.413	-0.33	0.479	-0.28	0.004	-1.00
Ambiente Construído																	
walkability_index	Índice de walkability (ZscoreDiv+ZscoreDes+ZscoreDens)	-5.29	12.68	0.00	1.00	3.02	100.23	0.398	0.54	0.713	0.21	0.853	0.12	0.005	-1.77	0.501	0.36
Div_Diversity_	Diversidade - quantidade de tipos de actividades	0.00	6.00	4.45	-0.80	0.64	19.31	0.936	0.02	0.794	0.07	0.761	0.09	0.001	0.88	0.747	-0.08
Des_cn01	Conectividade - densidade de nós com três ou mais ligações	0.00	13.00	1.37	3.04	16.85											
Srq_Des_cn01	Sqr(Des_cn01)	0.00	3.59	1.02	0.70	1.18	21.14	0.494	-0.20	0.613	0.14	0.486	0.20	0.034	0.62	0.413	0.20
Den_DensRes_ha	Densidade Residencial (ha)	0.06	219.43	29.00	2.09	5.78	28.94	0.814	-0.08	0.853	-0.06	0.606	-0.18	0.006	0.93	0.749	-0.09
AIR_PM10_2010	Concentração média Anual de PM10 (UG/m3) 2010	7.22	36.08	20.58	0.12	-1.02	5.27	0.930	-0.01	0.030	-0.29	0.526	-0.09	0.478	0.10	0.746	0.04
Mobilidade																	
Mov_TPTS	Pop. Resid que utiliza transpor públicso e modos activos diaramente (%)	20.64	85.55	45.68	0.28	-0.59	3.78	0.287	0.13	***	0.50	0.024	0.28	0.959	0.01	0.012	0.26
Mov_DMMP	Duração média dos movimentos pendulares	17.50	35.24	25.55	0.22	-0.30	2.06	0.276	0.10	0.199	-0.11	0.027	-0.20	0.717	-0.03	0.062	-0.14
Saúde - Internamentos																	
Tx_Diabetes	Taxa de internamento por diabetes (n.º por 100.000 habitantes.)	0.00	604.11	143.82	1.56	5.00		R^2=0.143									
Tx_Doencascirculatorio	Taxa de internamento doenças do sistema circulatorio (n.º por 100.000 hab.)	66.61	8213.26	1571.25	3.59	22.36											
Sqr_Tx_circulatorio	Sqr(Tx_Doencascirculatorio)	8.16	90.63	38.65	1.47	6.99				R^2=0.286							
Tx_Doencasrespiratorio	Taxa internamentos por doenças do aparelho respiratório (n.º por 100.000 hab.)	66.61	3602.31	1164.56	0.94	2.23						R^2=0.158					
Tx_Asma	Taxa de internamentos por asma (número por 100.000 hab.)	0.00	281.69	28.25	3.06	18.17											
Sqr_Tx_Asma	Srq(Tx_Asma)	0.00	16.78	4.31	0.23	0.11								R^2=0.168			
Tx_Hipertensao	Taxa de internamentos por Hipertensão (número por 100.000 hab.)	0.00	1118.57	139.01	2.65	11.53											
SqrTx_Hipertensao	Srq (Tx_Hipertensao)	0.00	33.45	10.43	0.63	1.20										R^2=0.390	

O modelo final representado na figura 1 descreve o modelo teórico a testar identificando a negrito os valores de regressão estandardizada (β) estatisticamente significativos para p<0.001. Como é possível verificar, o indicador de *walkability,* para além de um impacto direto (β=0.28 e p=0.03), tem os impactos mais fortes de todo o modelo nas variáveis qualidade do ar (AIR_PM_2010) e na variável relacionada com o uso dos transportes públicos e ativos (Mov_TPTS). A variável da Mov_TPTS é também estatisticamente significativa para a explicação dos internamentos por hipertensão. Esta é, aliás, a variável com valor mais alto (β =0.30; p<0.001), seguida do índice de *walkability* (β=0.28, p=0.03) e, finalmente, da duração média dos movimentos pendulares (β=-0.22 e p<0.001). Com este modelo é possível verificar a importância do *walkability* para a explicação dos internamentos, mas também o seu contributo para a melhoria da qualidade do ar, assim como a relação com o uso dos transportes públicos e dos modos ativos.

Os resultados apresentados estão em linha com a literatura internacional, no entanto, inovam com a introdução do contexto mediterrânico numa altura em que a investigação ainda se centra maioritariamente nos EUA e em poucos países da Europa. Os resultados reforçam ainda a importância das questões da mobilidade para o estado de saúde da população e a importância no desenho das cidades para a promoção da mobilidade sustentável e ativa, com comprovados efeitos na saúde.

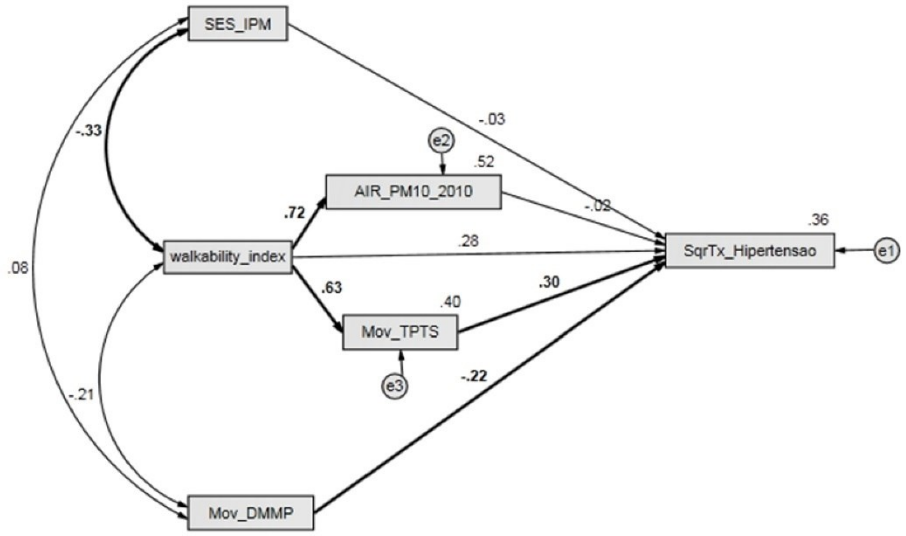

Figura 1 - Modelo de análise de trajetórias dos internamentos por hipertensão, com indicação dos coeficientes estandardizados, a negrito os estaticamente significativos (p<0.001).

Os resultados deixam ainda algumas questões que exigem maior investigação. Neste caso, a pouca importância das condições socioeconómicas para a explicação dos internamentos hospitalares, algo contraditório à literatura existente para Lisboa (Gotsens et al., 2013). Por outro lado, maior investigação deverá ser feita na relação do ambiente construído e as condições socioeconómicas que na AML se mostram relacionadas com o índice de walkability (β=-0.33, p<0.001). A conclusão que se pode tirar com base no modelo é que as características socioeconómicas têm uma influência direta reduzida na saúde, contudo, o não acesso a desenho urbano de qualidade e, consequentemente, menor acessibilidade e exposição a locais com pior qualidade do ar, originará piores condições de saúde. O desenvolvimento de modelos futuros deverá equacionar esta relação menos direta das condições socioeconómicas no estado de saúde da população. Porém, uma escala mais detalhada de que a escala da freguesia poderá ser explorada, reconhecendo à partida limitações de dados de saúde disponíveis a esse tipo de escalas. Outro aspeto importante é que os internamentos hospitalares são a situação mais tardia do estado de saúde, quando é necessário o seu tratamento urgente. O estudo não contempla toda a restante população que poderá sofrer deste tipo de doenças, mas que não recorre ou recorreu aos serviços hospitalares para o seu tratamento.

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5.2 II. The relationship between built environment and health in the Lisbon Metropolitan area – can walkability explain diabetes' hospital admissions?

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The relationship between built environment and health in the Lisbon Metropolitan area – can walkability explain diabetes' hospital admissions?

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A B S T R A C T

Introduction: Type 2 diabetes is one of the non-communicable diseases with higher increasing incidence across the world. Portugal is one of the most affected countries with this increase. Most risk factors for diabetes are modifiable and can be changed by a supportive built environment. The walkability index has been wildly used as concept to describe a healthy built environment. However, the ecological view of health and diabetes identifies the necessity of a multilevel intervention to the creation of a supportive built environment.The goal of this paper is to evaluate the association between walkability indicators and hospital admissions due to diabetes, in the Lisbon Metropolitan Area, by different methods through a proposed ecological model.

Methods: The built environment characteristics were evaluated using walkability measures including density, diversity and design, but also air quality and green areas availability. The socio-economic characteristic was controlled by the most common indicators, but it also included house size and house cost. The diabetes incidence was measured by hospital admissions due to diabetes. The statistical analysis was performed by a path analysis model that allows to consider the complexity of several effects on diabetes.

Results: The results show that built environment influences diabetes through air pollution and active travel. The proposed conceptual model explains 27% of the variance of hospital admissions due to diabetes. Additionally, the mediating variables active travel and air pollution had the variance explained in 73% and 70% respectively.

Conclusions: The results stress the non-direct influence of the built environment in health, showing that health can be improved through the promotion of active travel and the improvement of air quality. The improvement of these aspects is relevant at different levels of intervention, revealing the importance of the civil parishes level. The results reinforce the importance of policies at different levels to effectively change behaviour.

1. Introduction

Diabetes is one of the four major non-communicable diseases (WHO, 2016). On a global level, in 2014, an estimated 422 million adults had diabetes. The global prevalence (age-standardised) of diabetes has approximately doubled since 1980, when 108 million adults had diabetes, rising from 4.7% to 8.5%, according to the World Health Organization (WHO, 2016). Over the past decade, diabetes incidence has increased faster in low-and middle-income countries than in high-income countries (WHO, 2016). In Europe, Portugal is one of the countries with higher diabetes prevalence, at over 9%, on a par with Greece and France (WHO, 2016).

There are two types of diabetes, type 1, which is insulin-dependent and type 2, which was formerly called non-insulin-dependent. The cause of type 1 is not known and currently not preventable. Type 2 diabetes comprises the majority of the cases in the world and

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also in Portugal (WHO, 2016). The increased risk of type 2 diabetes is determined by an interaction of genetic and metabolic factors, as well as features such as ethnicity, family history of diabetes combined with older age, overweight and obesity, unhealthy diet, physical inactivity and smoking. Moreover, type 2 diabetes is largely preventable. A number of risk factors, such as obesity and physical inactivity, are modifiable and can help reduce the problems related to diabetes (OECD, 2016). Additionally, individuals with diabetes have a higher risk of suffering from other health complications such as cardiovascular and respiratory diseases (Brown et al., 2004).

The WHO attributes the growing of diabetes to population's ageing, obesity, unhealthy diets and sedentary lifestyles related to urbanisation and industrialisation (McKinlay and Marceau, 2000). The built environment can create a supportive social and physical context for healthy lifestyles, being a key aspect of type 2 diabetes prevention (WHO, 2016). The WHO Global report on diabetes suggests that no single policy or intervention can assure the creation of a supportive social and physical context for healthy lifestyles. The creation of a healthy environment requires an intersectoral approach, including all sectors, to consider the health impact on domains such as agriculture, finance, transport, education and urban planning. (WHO, 2016).

A systematic approach to the creation of a supportive built environment to health habits is made at different scales with different interventions and policies. However, most of the research about the relationship between built environment and health tends to be very closely related to the impact of the surrounding built environment, which could be defined as the bespoke neighbourhood (Feng et al., 2010; Saelens and Handy, 2008). Comprehensive population-wide approaches involve the analysis at different scales and methods (Roux, 2001). The promotion of a more active life, specially through the selection of active modes of transportation such as walking, cycling and even public transport is an important example.

The concept of walkability has been used as a measure to describe the characteristics of the built environment that support a walkable and healthy lifestyle (Hajna et al., 2015; Hassen and Kaufman, 2016; Saelens and Handy, 2008; Zapata-Diomedi and Veerman, 2016). This paper brings the case study of Lisbon introducing the southern Europe context, which is currently missing in the literature. Moreover, it explores the important role of active travel for shaping health results in a city with high car use (INE, 2018).

The goal of this paper is to evaluate the association between walkability indicators and hospital admissions due to diabetes in the Lisbon Metropolitan Area, by different methods through a proposed model (Fig. 1).

2. A conceptual framework of the association between built environment and diabetes

The complexity of health demands the use of ecological models to describe the influences of different environments and policies on changing individual behaviours, while considering social and psychological influences (Roux, 2001). Ecological models consider multiple levels of influence, suggesting more comprehensive interventions at different levels (Sallis et al., 2008).

The ecological models can guide comprehensive population-wide approaches to change behaviour, which can improve health (Sallis et al., 2008). The main purpose of ecological models is to address the multiple levels in which individual behaviour is influenced, including personal, interpersonal, community, organizational, physical, environment and policy aspects (Giles-Corti et al., 2005; Sallis et al., 2006).

The diagram in Fig. 1 represents the proposed framework that is the base for this research paper. Several direct and indirect effects were tested with the aim of explaining hospital admissions due to diabetes. We considered only built environment characteristics influencing the walkability measures, active travel behaviour, air quality, and green areas. These dimensions were considered because previous literature showed their influence on non-communicable diseases and/or on physical activity (Brown et al., 2004; Diez Roux et al., 2016; Lovasi et al., 2012; Sun and Yin, 2018). The conceptual framework presented follows other studies that propose conceptual frameworks to explain health through the built environment, considering complex effects and mediation relationships concerning green area, air pollution or physical activity (Su et al., 2016; Wang and Lan, 2019). In fact, one of the most important roles of the built environment in promoting health is through physical activity (Sallis et al., 2012; Van Cauwenberg et al., 2016).

The next sections will support the inclusion of several variables of the conceptual framework based on previous research.

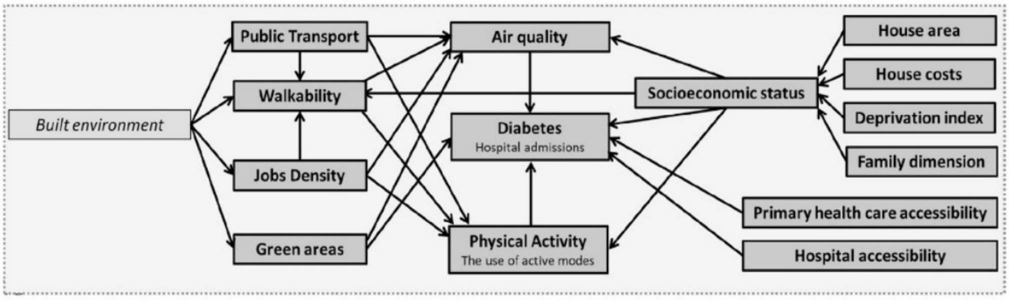


Fig. 1. Conceptual framework.

2.1. Physical activity

In the conceptual model of Fig. 1, physical activity is a key point as a mediating variable in the relation between built environment characteristics and non-communicable diseases. Indeed, physical activity has an important contribution to the prevention and control of non-communicable diseases, being also important in the treatment and rehabilitation processes (Ding et al., 2016; Guthold et al., 2018; Sallis et al., 2012).

Physical activity can be affected in four areas of daily life, related to how people occupy their time (Sallis et al., 2012, 2004). First, the leisure or recreation time, including physical activity. Second, the type of occupation (blue versus white collar), with different levels of exercise required. Third, the transportation options, namely the possibility of using of active modes or the availability to use motorised modes. Finally, household daily routines, such as cleaning or gardening. The four areas are determined by diverse built environment features and policies (Sallis et al., 2012, 2004). The built environment can have a stronger influence on the leisure and transportation dimensions (Saelens et al., 2014).

2.2. Active travel

'Active travel' is the transportation mode that requires higher levels of physical activity, and not only includes walking and biking, but also the use of public transportation. Transport choices affect individual health. On the one hand, several studies show recurrent car users as having a higher incidence risk of non-communicable diseases (Frederick et al., 2018; Saelens et al., 2014). On the other hand, individuals that resort to walking, cycling, and travelling by public transport have a higher probability of achieving the recommended amount of physical activity (Martin et al., 2014; Yang and French, 2013). In that way, it is important to consider aspects of mobility and commuting patterns in a conceptual framework to explain health outcomes. Changing mobility behaviour requires a major strategic and systematic approach in interventions and policies on built environment to promote a more sustainable and active type of transportation. Recent studies suggested that active travel is most influenced by the built environment, even for the different scale of analysis at different levels and different surrounding contexts (Learnihan et al., 2011). The increase in active travel has an impact on health status as a result of the associated increase in physical activity, but also by its impact in improving air quality in the city (Rissel et al., 2012).

2.3. Air quality

The inclusion of air quality in the conceptual framework is justified as a proxy for street traffic and consequence of the transportation choices, and it has a significant public health impact, increasing the risk of death from several causes and being related to many diseases (Health Effects Institute, 2018). Moreover, the increase or reduction of air pollution is closely related to the built environment. The presence of green areas can contribute to decreased pollution levels (Khreis et al., 2016). In the same way, increasing active travel can lead to reductions in air pollution. However, higher amounts of active travel in a more polluted area can result in higher inhalation of polluted air (Sun et al., 2017).

2.4. Walkability

The concept of walkability describes how favourable the built environment characteristics are for people to walk. Usually this concept is measured through a composite index accounting different indicators relevant for walkable places (Saelens and Handy, 2008).

The classification of built environment features that favour walking are provided by travel behaviour studies and were classified by Cervero and Kockelman (1997) under three main categories as 3Ds: density, diversity, and design. Later, the 3Ds were expanded to 5Ds to include destination accessibility, and distance to transit (Ewing and Cervero, 2010). Furthermore, the authors Vale and Pereira (2016) suggested that the latter two D's should be considered accessibility measures. The authors suggested that accessibility acts as a mediator in the relationship between the built environment and walking behaviour. Accessibility should be explicitly measured to explain walking and be conceived not as a dimension of the built environment, but a result of it. The D's approach is only one possible organization of the built environment indicators to explain walking. Depending on the scale of analysis and the detail of data, different methods can be applied. Recent authors suggest a new framework based on a different organization of built environment indicators and propose the creation of a new one for street audit (Su et al., 2019).

The commonly used 'walkability index' was coined by Frank et al. (2005) to express the qualities of the built environment that are associated with physical activity. The walkability index considers three major dimensions: land-use mix, residential density, and street connectivity. Several health studies use the walkability concept to explore the relationship between built environment and health results and find a significant relationship between walkability and several health outcomes, such as obesity levels, hypertension incidence and diabetes (Loo et al., 2017; Sundquist et al., 2015; Van Cauwenberg et al., 2016).

Diabetes has also been related to walkability, showing an inverse association between neighbourhood walkability and incidence of type 2 diabetes, and this association remained significant, regardless of neighbourhood deprivation (Sundquist et al., 2015). Yu et al.

(2017) concluded that there is a relationship between hospital admissions due to diabetes and walkability – they found that the cost per person of hospital admissions was inversely and statistically significantly, associated with the walkability measure used, in this case, the Walk Score® measure. Another study from China relates several built environment characteristics to different diseases and concluded that walkability and connectivity measures are important influences on type 2 diabetes (Su et al., 2016). These findings are particularly important because it is known that type 2 diabetes is mainly related to aspects of behaviour. Additionally, neighbourhoods with higher walkability registered fewer hospitals admissions, highlighting the impact of good walkability on reducing hospital admissions, and, consequently, healthcare costs (Yu et al., 2017).

2.5. *Green areas*

The literature highlights green areas as important determinants of health (Gascon et al., 2016; Tzoulas et al., 2007; WHO Regional Office for Europe, 2016). Moreover, accessibility to green areas and green parks contributes to increase the amount of physical activity (Bancroft et al., 2015; Nielsen and Hansen, 2007; Schipperijn et al., 2013; World Health Organization Regional Office for Europe, 2016). Other study concludes that green areas are negatively associated with most of the non-communicable diseases (Su et al., 2016). Additionally, green areas may play an important role in minimizing air pollution issues, contributing to air renovation (Khreis et al., 2016). Finally, green areas can play an important role in reducing socio-economic inequalities (Wang and Lan, 2019).

2.6. *Socioeconomic status*

Socioeconomic status is the main shaper of individual life results (Marmot et al., 2012). Socioeconomic status characteristics have an impact on social connections and life achievements (Burchardt, 2000; Marmot et al., 2012). Despite the most frequent indicators of socioeconomic status being income and financial measures, several authors show that money is not the main player for individual health and wellbeing (Kent et al., 2017; Nordbakke and Schwanen, 2014). The house characteristics are crucial to define spatial localization, and the property value of the space is the first individual built environment context. As a consequence of property value, built environment inequalities are emphasized (Drewnowski et al., 2016; Jiao et al., 2016). In fact, built environment plays a crucial role in emphasizing the social inequality gap between different social groups (Delbosc and Currie, 2011) and their access to important facilities in the city, such as health facilities or green areas (Wang and Lan, 2019). Moreover, the odds of incidence of diabetes is more

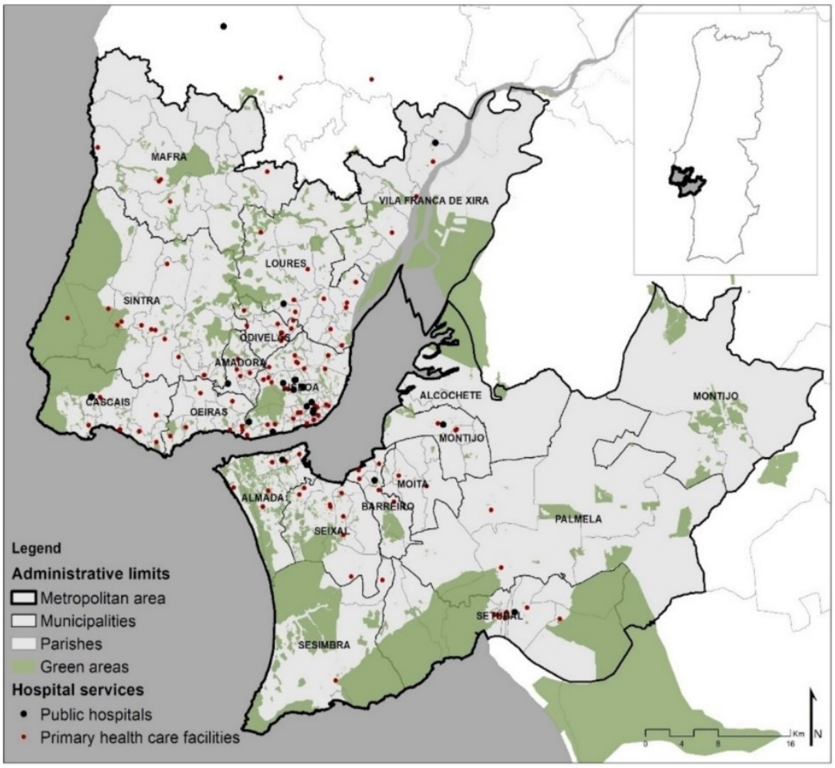


Fig. 2. Study area.

Table 1
Used indicators, descriptive statistics, sources of data and year.

Abbreviations	Indicator	Source	Descriptive Statistics			Weighted variables		
			Min	Max	Mean	Skew.	Kurtosis	VIF[1]
Socio-economic								
HouseNoToilet	Households without toilet (%)	INE 2011	0.00	3.60	0.34	4.99	41.04	
SqrHouseNoToilet	*Sqr(Households without toilet) - square root transformation*	INE 2011				1.59	4.66	
HighEducation	Proportion of living people with high education concluded (%)	INE 2011	4.00	56.49	20.48	1.11	0.67	
AverageAge	Average age in parish	INE 2011	30.63	51.44	42.05	0.14	-0.17	5.54
Illiteracy	Illiteracy rate (%)	INE 2011	0.75	13.58	3.89	1.56	5.22	
Employment	Employment rate (%)	INE 2011	6.54	27.60	12.62	0.74	1.93	
MaterialDeprivation	Material Deprivation index 2011	INE 2011	-3.85	10.20	0.00	1.24	4.04	2.85
HouseArea	Average house area (m2)	INE 2011	41.81	137.29	96.64	0.08	0.04	7.17
HouseCost	Costs with housing aquisition (euros per month)	INE 2011	282.68	643.20	445.97	0.32	-0.43	
CrowdedHousehold	Proportion of private households in conventional dwellings overcrowded (%)	INE 2011	4.42	27.16	13.09	0.77	0.63	3.76
OnePersonsHousehold	Households with one element family	INE 2012	14.05	50.57	26.81	0.55	-0.55	
Built Environment								
Walkability_Index	Walkability index	Authors	-5.29	12.68	0.00	0.66	2.45	3.76
ActivitiesVariety	Diversity - number of types of activities	Naveteq	0.00	6.00	4.45	-0.72	0.42	
ComercialDensity	Number of activities divided by the civil parish area (ha)	Naveteq	0.00	7.52	0.55	5.39	33.92	
SqrComercialDensity	*Sqr(Div_ComercialDensity) - square root transformation*	Naveteq				2.60	9.38	
Connectivity	Connectivity - density of street intersection with three or more link connections (ha)	Naveteq	0.00	13.00	1.37	2.19	16.67	
Srq_Connectivity	*Srq(Connectivity) - square root transformation*	Naveteq				-0.14	0.93	
ResidentialDensity	Residential density (ha)	INE 2011	0.06	219.43	29.00	1.84	4.76	
JobsDensity	Density of jobs (ha)	Quadros pessoal 2011	0.02	297.92	24.65	4.39	22.85	
SrqJobsDensity	*Sqr(JobsDensity) - square root transformation*	Quadros pessoal 2011				2.16	6.04	4.53
Green_PerCapita	Sum of green area (ha) divided by the population	Openstreetmap	0.00	11609.47	410.96	5.58	38.06	
Log10Green_PerCapita	*Log10(Green_PerCapita) - logarithm base 10 transformation*	Openstreetmap				-0.54	4.35	1.77
AirPollution	Annual average concentration PM10 (UG/m3)	Small Area Health Statistics Unit (SAHSU) 2010	7.22	36.08	20.58	0.17	-0.89	3.88
Accessibility								
CommutingTime	Average commuting time	INE 2011	17.50	35.24	25.55	-0.04	-0.32	2.62
TravelTime_Hospital	Average travel time from each census track to nearest hospital (minutes)	calculated using ArcGIS Pro online service	2.46	49.17	11.91	1.24	2.70	1.65
TravelTime_PHCF	Average travel time from each census track to nearest primary health care facility (minutes)	calculated using ArcGIS Pro online service	1.39	46.55	5.63	5.51	60.06	
Log10TravelTime_PHCF	*Log10(TravelTime_PHCF) - logarithm base 10 transformation*	calculated using ArcGIS Pro online service				0.88	2.02	1.59
PublicTransport	Daily public transport supply		0.00	3868.00	581.79	1.75	2.34	
Physical activity								
ActiveTravel	Daily use of active modes for commuting(%)	INE 2011	20.64	85.55	45.68	0.11	-0.58	6.32
Hospital admissions								
TIP_Diabetes	Rate of hospital admissions due to diabetes (ICD9: 250)	Administração Central do Sistema de Saúde (2008–2012)	0.00	519.83	141.75	0.94	3.39	

INE 2011: Instituto Nacional de Estatística, population census 2011

1) Only for the indicatores used in the final path analysis

than twice as likely in people with the lowest level of education (OECD, 2016; Santana et al., 2015). People with lower levels of education frequently have poorer nutrition and are more likely to be obese, all of which are important risk factors for diabetes. (OECD, 2016). Lower socioeconomic status also increases the odds of risk behaviours. In that way, socioeconomic status is a critical covariate to model the impacts of the city on diabetes incidence (Brown et al., 2004).

2.7. *Accessibility to health care facilities*

The primary care facilities play an important role as a first response to health situations but also the first level of health promotion and disease control (Vaz et al., 2014). In Portugal, the primary health care facilities accommodate several programs to control the different no-communicable diseases including diabetes. The function of primary health facilities to control individual's level of diabetes can prevent diabetes crisis complications that can reduce the number of hospital admissions (Biscaia and Heleno, 2017; Vaz et al., 2014). In the case of hospital facilities, previous studies have shown that higher proximity to a hospital leads to a higher use of these facilities (Nicolau et al., 2009). A model to explain hospital admissions should adjust and control for the possible confounder of distance to hospital.

3. Data and methods

3.1. *Study area*

The study area (Fig. 2) presents the Lisbon Metropolitan Area, a regional administrative division composed of 18 municipalities and 211 civil parishes. The Lisbon Metropolitan Area represents 3.3% of the total area of Portugal, with approximately 3 million inhabitants (25% of the Portuguese population). In economic terms, it represents more than 36% of the national Gross Domestic Product. The goal of the paper is to assess the link between built environment characteristics and hospital admissions due to diabetes. However, the data on health results is limited, due to confidentiality issues, and it is only available at civil parish level. This fact determines the detail of analysis at the civil parishes' aggregation level.

3.2. *Indicators*

Table 1 describes the source and the descriptive statistics of the indicators used. The collection of indicators covers the dimensions of the conceptual framework from Fig. 1.

The data originate from different sources collected at the level of the parish and it were selected in order to represent five dimensions of analysis: i) socio-economic; ii) built environment characteristics; iii) accessibility, iv) physical activity; and v) hospital admissions (Table 1).

3.3. *Socioeconomic status measures*

3.3.1. *House costs and house size*

The paper introduces indicators to measure the socioeconomic status context by the characterization of the house size as well as the house costs. The house cost and transportation cost correspond to the higher proportion of household income utilization. This can be a proxy for socioeconomic status and it can also describe the type of urban development and occupation (Drewnowski et al., 2016; Jiao et al., 2016). The house size has a clearer meaning when considering household family size. In this way, we also collect the information about the household size. In this case, we evaluate the proportion of one element household and the proportion of private households in conventional dwellings overcrowded. These indicators are available at Statistics Portugal (www.ine.pt).

3.3.2. *Material deprivation index*

Considering the individual and contextual socioeconomic status characterisation, we constructed a material deprivation index to assess the general deprivation situation of the individuals living in each parish, following Carstairs and Morris's (1990) method. The material deprivation index was based on the following indicators: (1) illiteracy rate; (2) employment rate; and (3) percentage of households without a toilet. The indicators were standardized, and the *z-scores* were summed to form the composite material deprivation index, in which higher values mean higher deprivation, and 0 represents the average of all civil parishes (Carstairs and Morris, 1990).

3.4. *Built environment*

3.4.1. *Walkability index*

The proposed walkability index follows the index by Frank et al. (2005) and assesses the three most cited dimensions: density, diversity, and design (Cervero and Kockelman, 1997). The final walkability index is given by the sum of the *z-scores* of each indicator.

The density dimension was measured by household density, using the household number on each civil parish from INE and divided by the civil parish area. Diversity was measured by the number of types of activities obtained from points of interest information in Navteq data source (https://www.here.com/navteq). Unlike Frank et al. (2005), who use entropy measures, we used a simpler idea of diversity, conceived around the concept of variety. Accordingly, points of interest were classified into six types of activities - retail, entertainment, civic and institutional, food-related, office, and recreation - and the resulting diversity indicator varies between 0 and 6, in accordance to the number of types of activities present in the civil parish (see Appendix A, Table 4). Finally, the design dimension is measured with a connectivity measure, namely the density of street intersections (nodes) with three or more links divided by area of civil parish. The street network used was obtained from Navteq road centreline network, excluding roads prohibited to pedestrians such as highways. Beyond the indicators used in the walkability index, we also evaluated other indicators to test their relevance for improving a future walkability index. In the case of density dimension, we tested jobs density to explain active travel. The employment data used are available for civil parish level (*Quadros de Pessoal do Ministério da Solidariedade, Emprego e Segurança Social*). In the case of diversity dimension, we evaluated the dispersion of these activities calculating the activities density.

3.4.2. Green area

Data on green area were collected from *openstreetmap* (http://www.openstreetmap.org) a collaborative and crowdsourced website for cartography data created by users contribution. The green area was selected based on the following classifications: 'allotments', 'forest', 'grass', 'meadow', 'nature reserve', 'park', and 'recreation ground'. In the class 'nature reserve', we opted to remove the *Reserva Natural do Estuário do Tejo (estuarina)* [Tagus Estuary Natural Reserve] and the special protection zone of Cabo Espichel since its status gives it conditioned access and reduced number of residents. The indicator used was the green area per capita due to its relation to planning tools and their frequent use in literature (Kabisch and Haase, 2014; Wang and Lan, 2019).

3.4.3. Air quality

Air quality was measured by the annual average concentration PM_{10} (μG/m3) 2010. The data, at parish level, was estimated through a land use occupation model (LUR - Land Use Regression Model) with a 100 m × 100 m spatial resolution, according to Hoogh et al. (2016). The data from air quality source were spatially analysed to produce the parish averages of annual mean PM_{10} (UG/m3) (by averaging the 100 m × 100 m centroids across a parish) (de Hoogh et al., 2016; Vienneau et al., 2013). Data were collected from the Eurohealthy data platform (available at https://eurohealthydata.uc.pt for authorised users).

3.4.4. Accessibility

The use of healthcare facilities is influenced by their accessibility (Nicolau et al., 2009; Vaz et al., 2014). As such, we evaluated the travel time between each census track of the Lisbon Metropolitan area to the closest hospital equipped with emergency services (see Appendix B, Table 5). The analysis considered the travel time on a Tuesday at 8 a.m. The results of each census tracks were averaged for the civil parish. In this way, we try to reduce the error associated with the different accessibilities across civil parish boundaries. The analysis was made using the ArcGIS pro networks analyst with traffic information considering congestion and street speed. The same approach was used to measure accessibility to primary health care facilities, in this case, the "*Centros de saúde*" and their extensions (Biscaia and Heleno, 2017). The data comes from the National Health Care Service website *(*https://www.sns.gov.pt/sns/pesquisa-prestadores/*)* and the location at googlemaps.

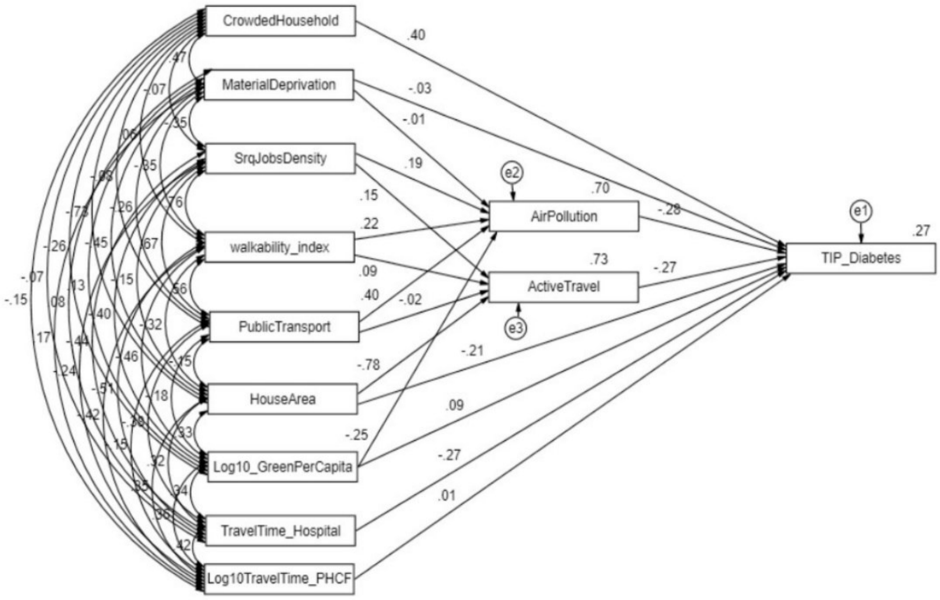
Another important aspect that influences health in a broader view is the individual commuting transportation mode (Frederick et al., 2018; Saelens et al., 2014). For this, we account for the average commuting time for each parish available at the National Statistics Institute (INE). The commuting time is directly related to mobility options. In the case of the active travel, the public transport supply is crucial to its use. In this way, we considered the total daily supply of public transport in each parish. Public transport accessibility was measured following Currie and Delbosc's (2010) methodology, adapted to the LMA context by considering station buffers sizes of 400 m to bus, 800 m to train, 500 m to tram and 800 m to ferryboat. The public transport indicator consists in daily transport supply in each walking buffer, which is calculated by the proportion of overlapped buffers in civil parishes.

4. Active travel

We measure physical activity by proxy through the active travel information. The used information concerns commuting by walking, biking, and public transportation modes. This information narrows the scope of analysis for the active population that commutes daily.

5. Hospital admissions by diabetes

We selected public health admissions due to diabetes (ICD9: 250) as our dependent variable of analysis; each hospitalization record has information on the patient's parish of residence. The standardized hospital admission rate due to diabetes were collected for the



			Estimate	S.E.	p	β
AirPollution	<---	PublicTransport	0.00	0.00	***	0.40
TIP_Diabetes	<---	CrowdedHousehold	5.69	0.01	***	0.40
AirPollution	<---	walkability_index	0.87	0.00	***	0.22
AirPollution	<---	SrqJobsDensity	0.47	0.00	***	0.19
ActiveTravel	<---	SrqJobsDensity	0.64	0.00	***	0.15
TIP_Diabetes	<---	Log10_GreenPerCapita	5.01	0.04	***	0.09
ActiveTravel	<---	walkability_index	0.60	0.00	***	0.09
TIP_Diabetes	<---	Log10_TravelTimeCS	3.48	0.19	***	0.01
AirPollution	<---	MaterialDeprivation	-0.03	0.00	***	-0.01
ActiveTravel	<---	PublicTransport	0.00	0.00	***	-0.02
TIP_Diabetes	<---	MaterialDeprivation	-1.05	0.02	***	-0.03
TIP_Diabetes	<---	HouseArea	-0.85	0.01	***	-0.21
AirPollution	<---	Log10_GreenPerCapita	-1.54	0.00	***	-0.25
TIP_Diabetes	<---	ActiveTravel	-1.33	0.01	***	-0.27
TIP_Diabetes	<---	TravelTime_Hospital	-2.58	0.01	***	-0.27
TIP_Diabetes	<---	AirPollution	-2.51	0.01	***	-0.28
ActiveTravel	<---	HouseArea	-0.63	0.00	***	-0.78

*** p <0.001

Fig. 3. Path analysis to explain hospital admissions for diabetes (all the variables are statistically significant to $p < 0.001$).

period between 2012 and 2018. This measure was calculated as a weighted average of the age-specific hospitalizations rates of the European Standard Population.

$$SDRA = \frac{\sum_x (A_{mx}\, S_{Px})}{\sum_x S_{Px}}$$

SDRA = age standardised hospital admission rate for populations in region A
A_{mx} = age-specific hospital admission rate at age x last birthday in population in region A
S_{Px} = population exposed to the risk of hospitalization at age x last birthday in the standard population

6. Statistical analysis

In order to understand the complex process and select the significant variables with a relation with health, in particular diabetes, we performed a sequence of three steps of statistical analysis to model the path analysis, using SPSS-AMOS version 24. Path analysis is an extension of multivariate linear regression and is used to study structural relationships, direct and indirect effects, between variables based on correlation structure observed on the variables (Wright, 1934).

In the first step, we weight civil parishes according to their population because there is a difference in the number of residents. We use the weight data tool implemented in SPSS 24, and weighed the civil parishes based on number of residents. We used this file to create a sample correlation matrix to be used as input to the path analysis instead of the raw data. After, a univariate statistical analysis was developed to evaluate the descriptive statistics distribution and identify outliers. We assessed normal distribution based on skewness values lower than 2 ($|sk|<2$) and kurtosis values lower than 7 ($|Ku|<7$). We transformed variables without a normal distribution to increase normality (see Table 1).

Table 2
Covariance matrix of the variable of path analysis.

Covariances: (Group number 1 - Default model)						
			Estimate	S.E.	p	β
walkability_index	<->	SrqJobsDensity	3.06	0.00	***	0.76
PublicTransport	<->	SrqJobsDensity	1394.20	1.49	***	0.67
walkability_index	<->	PublicTransport	728.23	0.89	***	0.56
MaterialDeprivation	<->	CrowdedHousehold	2.98	0.89	***	0.47
TravelTime_Hospital	<->	Log10TravelTime_PHCF	0.43	0.00	***	0.42
Log10_GreenPerCapita	<->	Log10TravelTime_PHCF	0.07	0.00	***	0.36
HouseArea	<->	Log10TravelTime_PHCF	0.86	0.00	***	0.35
Log10_GreenPerCapita	<->	TravelTime_Hospital	1.94	0.00	***	0.34
HouseArea	<->	Log10_GreenPerCapita	4.55	0.01	***	0.33
HouseArea	<->	TravelTime_Hospital	25.01	0.05	***	0.32
MaterialDeprivation	<->	Log10TravelTime_PHCF	0.05	0.00	***	0.17
MaterialDeprivation	<->	Log10_GreenPerCapita	0.23	0.00	***	0.13
MaterialDeprivation	<->	TravelTime_Hospital	0.81	0.01	***	0.08
walkability_index	<->	CrowdedHousehold	0.35	0.00	***	0.06
SrqJobsDensity	<->	CrowdedHousehold	-0.70	0.01	***	-0.07
CrowdedHousehold	<->	TravelTime_Hospital	-1.58	0.01	***	-0.07
PublicTransport	<->	CrowdedHousehold	-257.35	1.88	***	-0.08
PublicTransport	<->	Log10TravelTime_PHCF	-21.46	0.09	***	-0.15
HouseArea	<->	SrqJobsDensity	-5.15	0.02	***	-0.15
CrowdedHousehold	<->	Log10TravelTime_PHCF	-0.10	0.00	***	-0.15
HouseArea	<->	PublicTransport	-1731.80	6.81	***	-0.15
Log10_GreenPerCapita	<->	PublicTransport	-149.23	0.50	***	-0.18
SrqJobsDensity	<->	Log10TravelTime_PHCF	-0.11	0.00	***	-0.24
MaterialDeprivation	<->	PublicTransport	-354.36	0.84	***	-0.26
Log10_GreenPerCapita	<->	CrowdedHousehold	-1.01	0.00	***	-0.26
HouseArea	<->	walkability_index	-6.95	0.01	***	-0.32
MaterialDeprivation	<->	walkability_index	-0.92	0.00	***	-0.35
MaterialDeprivation	<->	SrqJobsDensity	-1.48	0.00	***	-0.35
PublicTransport	<->	TravelTime_Hospital	-1762.55	2.99	***	-0.38
Log10_GreenPerCapita	<->	SrqJobsDensity	-1.02	0.00	***	-0.40
walkability_index	<->	Log10TravelTime_PHCF	-0.12	0.00	***	-0.42
SrqJobsDensity	<->	TravelTime_Hospital	-6.34	0.01	***	-0.44
MaterialDeprivation	<->	HouseArea	-10.27	0.02	***	-0.45
Log10_GreenPerCapita	<->	walkability_index	-0.74	0.00	***	-0.46
walkability_index	<->	TravelTime_Hospital	-4.60	0.01	***	-0.51
HouseArea	<->	CrowdedHousehold	-38.30	0.04	***	-0.73

***$p < 0.001$.

In the second step (Appendix C, Table 6), we calculated a Pearson's matrix to assess the statistical association between variables. We used this information to identify pairs of correlated variables that we could remove without the risk of losing important information, which is the case of population age, percentage of population with higher education, one-person household, and commuting time. Moreover, the components used in the indices were removed and only the index was used. In the case of deprivation index the indicators removed was illiteracy rate; (2) employment rate; and (3) percentage of households without toilet. For the walkability index, was removed the activities variety, the connectivity and residential density. Additionally, the commercial density was also removed due to a higher correlation with the walkability index and jobs density.

Finally, in the third step, we developed a path analysis model to explain hospital admissions for diabetes, based on the conceptual framework of Fig. 1 and on the results of the previous steps. We created the model by testing different effect assumptions based on the correlations and association values that resulted from the previous steps, as well as on some insights from other studies that found correlation and influences between the analysed variables. We used a sensitivity analysis based on the explanation power of the model and the beta values of the variables to select the model with higher explanation power (see Appendix D, Table 7). The multicollinearity evaluation was made through the variance inflation factor (VIF) removing variables with values higher than 10 (Marôco, 2010). The path models also tested the possibility of mediating effects, resulting in the assumptions of two mediating variables.

7. Results

7.1. Path analysis

The path analysis model explains 27% ($R^2 = 0.27$) of the variance of hospital admissions due to diabetes (Fig. 3). Additionally, active travel and air pollution variable have their variance explained in 73% and 70% respectively. The results show that the crowded house is the most important indicator to explain hospital admissions due to diabetes ($\beta = 0.40$, $p < 0.001$). Air pollution is the second highest important indicator to explain hospital admissions due to diabetes ($\beta = -0.28$, $p < 0.001$), followed by travel time to hospital ($\beta = -0.27$, $p < 0.001$), and active travel ($\beta = -0.27$, $p < 0.001$). The results of the model show that the average house size is also important to explain hospital admissions due to diabetes ($\beta = -0.21$, $p < 0.001$). 70% of the variance of air pollution ($R^2 = 0.70$) was explained by material deprivation index, walkability index, green area per capita, public transport supply and jobs density. The public transport supply is the most important indicator to explain air pollution ($\beta = 0.40$, $p < 0.001$), followed by green area ($\beta = -0.25$, $p < 0.001$). The walkability index also has a higher importance in explaining air pollution ($\beta = 0.22$, $p < 0.001$). The active travel variance explained was 73% ($R^2 = 0.73$), described by the variables: jobs density, walkability index, public transport supply and house area. The house area is the most important indicator to explain active travel ($\beta = -0.78$, $p < 0.001$), followed by jobs density ($\beta = 0.15$, $p < 0.001$). The walkability index has a lower coefficient value to explain active travel ($\beta = 0.09$, $p < 0.001$). However, the results point that the higher walkable the place, the higher the amount of people using active travel. Surprisingly, public transport supply was the lowest value to explain active travel. This result is unexpected and can be explained by the big difference in public transport supply for the different civil parishes in the metropolitan area of Lisbon.

Accessibility to health care facilities have distinctive behaviour. On the one hand, accessibility to hospital has a negative relation ($\beta = -0.27$, $p < 0.001$), where the increasing distance to the hospital leads to a decrease in hospital admissions due to diabetes. On the other hand, accessibility to primary health care facilities suggests an increase in hospital admissions due to diabetes with the increase of distance to primary health care facilities ($\beta = 0.01$, $p < 0.001$).

The covariances of the independent variables, double arrow connections (best described in Table 2), point to interesting results in the relationship between the considered built environment indicators. For example, jobs density is strongly associated with the walkability index ($\beta = 0.76$, $p < 0.001$) and the public transport supply ($\beta = 0.67$, $p < 0.001$). The walkability index has higher values of covariance to indicators such as the public transport supply ($\beta = 0.56$, $p < 0.001$), the green area ($\beta = -0.46$, $p < 0.001$) and the travel time to hospital ($\beta = -0.51$, $p < 0.001$). This result suggests a cluster of built environment characteristics in the metropolitan area of Lisbon, suggesting that places with higher walkability characteristics are at the same time the places with more jobs density, better

Table 3
Standardized total effects on diabetes hospital admissions.

Variable	Direct effect	Indirect effect	Total effect
CrowdedHousehold	0.40	0.00	0.40
Log10_GreenPerCapita	0.09	0.07	0.16
Log10TravelTime_PHCF	0.01	0.00	0.01
HouseArea	-0.21	0.21	0.00
MaterialDeprivation	-0.03	0.00	-0.03
walkability_index	0.00	-0.09	-0.09
SrqJobsDensity	0.00	-0.09	-0.09
PublicTransport	0.00	-0.11	-0.11
ActiveTravel	-0.27	0.00	-0.27
TravelTime_Hospital	-0.27	0.00	-0.27
AirPollution	-0.28	0.00	-0.28

Standardized total effects on diabetes hospital admissions.

public transport supply and better accessibility to healthcare facilities.

The model assumes two mediating variables: active modes of transportation and air pollution. Air pollution mediates the statistical association between hospital admissions due to diabetes and five variables: material deprivation index, jobs density, public transport supply, walkability index and green area. The use of active modes of transportation mediates the statistical association between house area, walkability index, public transport supply and jobs density to explain hospital admissions due to diabetes.

The consideration of these mediating effects increases the explanation power of the model. Table 3illustrates the direct, indirect, and total effects of variables in hospital admissions due to diabetes. Evaluating the explanation of the hospital admissions due to diabetes the indicator crowed household has the highest direct effect ($\beta = 0.40$), followed by air pollution ($\beta = -0.28$). When considering the total effects, crowed household remains the variable that has the highest effect on hospital admissions due to diabetes ($\beta = -0.41$). In the mediation association, the house area is the variable with the highest indirect effect on diabetes ($\beta = 0.21$), followed by public transport supply ($\beta = -0.11$), contributing to diabetes through the two mediating variables (see Table 3).

8. Discussion

The present paper suggests a conceptual framework for one of the levels of the ecological models of diabetes. Type 2 diabetes is determined by an interaction of genetic and metabolic factors and several individual habits; however, the built environment context can support a changing in individual habits (WHO, 2016). The Portuguese context has suffered from an increase of diabetes incidence, particularly type 2 (WHO, 2016). The results of the paper suggest a statistical association of the indicators at parish level to explain the impact of the use of active travel on hospital admissions for diabetes. The proposed model suggests that nearly 27% of hospital admissions due to diabetes are influenced by the variables in our model. Additionally, the mediating variables active travel and air pollution had the variance explained in 73% and 70% respectively.

The indicators of 'house area' and 'house cost' constitute a different approach to measure socioeconomic status beyond the usual used indicators. The results emphasize the importance of housing characteristics to explain health, (Almendra et al., 2017; Drewnowski et al., 2016; Jiao et al., 2016), specially their influence on active travel reflected on the one hand by the socio-economic characteristics, but also by a different urban development in the LMA. These results suggest that civil parishes with bigger houses lead to a lower use of active modes.

The proposed path analysis model is an innovative approach to consider the complex effects of variables on the ecological model of health. This is quite important for diabetes, because this type of disease can be explained through an ecological model, being a cause of several health complications (Brown et al., 2004). Nevertheless, an ecological model doesn't account for the individual aspects that contribute to a higher incidence of different diseases, including diabetes (Roux, 2001).

The results of the path model for diabetes confirm the higher contribution of aspects from the built environment to influence hospital admissions for diabetes, considering mediating effects through the variables air pollution and active travel. The role of air pollution is complex and points to higher hospital admissions due to diabetes in civil parishes with lower air pollution. Once again this can reflect the differences in LMA with a significant presence of rural areas with lower air pollution, which are also the civil parishes with lower accessibility to health care facilities that lead to lower accessibility to health facilities (Su et al., 2016; Vaz et al., 2014). The green area confirms its role to improve air quality and the indirect effect of hospital admissions due to diabetes. However, the results indicate that the green area has a lower importance on active travel than initially expected. The type of green areas analysed, based on a broader concept of green area counting not only urban green areas, but also major landscape features such as forests, can explain this (Dennis and James, 2017). This is justified due to the scale of analysis exploring a macro scale contribution, mostly by the reduction of air pollution and the psychological impact on individuals from this type of landscape (Akpinar et al., 2016). Though, the type of green areas related to physical activity with impact on health have different characteristics that are not measured by the proposed indicator (Wang and Lan, 2019).

The proposed model considers air pollution and active transportation as mediating variables. In the case of active travel, the most important indicators are jobs density and house area. Public transport supply is not very important to explain active travel; however, it is the indicator with the highest indirect influence on diabetes. This result suggests it is necessary to acquire better information about commuting patterns to evaluate what really influences the use of active travel. In this case, jobs density clearly influences active travel. The covariance between built environment measures points to strong relationships between jobs density, public transport supply and walkability index. This is useful to understand and explore the creation of a walkability index that better explains active travel and even health results. The jobs density is an important indicator to be included in a walkability index, for instance, in the density dimension, due to its contribution to explain active travel.

The correlation between air pollution, walkability, and diabetes admissions indicate that where we find more walkable places, according to the walkability index, is also where air pollution is higher. This result can indicate that in Lisbon Metropolitan area, the most walkable places are not contributing to better air quality. This can confirm that 'cars follow people', and that the most walkable place is also where we have more traffic and air pollution (Marshall et al., 2009). Another possible reason is that the type of walkability index proposed can evaluate a good walkable place, yet, it misses the measure of a healthy place considering air pollution.

An important finding is the lower importance of the deprivation index to explain hospital admissions due to diabetes. The deprivation index is commonly used in several studies to explain health with significant importance (Roux, 2001), but not in this case. This is important because it brings the discussion of the deprivation characteristics of the individual versus built environment. The results stress the relative importance between individual deprivation indices measured by education and employment, comparing with neighbourhood context deprivation measured (in the present paper) by house cost and house size. This means that, for health outcomes, other aspect of the built environment and spatial segregation have a higher influence than the traditional socioeconomic status measures (Lucas et al., 2016). The introduction of house characteristics and their importance in the model brings a new insight on their importance, not only in terms of the physical characteristics as first layer of context (Sarkar et al., 2016), but also as income consumption that can reduce time and money for healthy activities (Yang and French, 2013). Other important indicator to the socioeconomic status description is the overcrowded household that reveals itself strongly related with hospital admissions due to diabetes. These results suggested a revision of the material deprivation indicator with inclusion of paraments such as house area or overcrowded information, and the possibility of removing others, for example, the house without toilets that can have a reduced prevalence in the developed countries context.

The analysis of the mediating effects of diabetes hospital admissions shows the need for further research on the direct and indirect effects of build environment on health. Moreover, the level of detail in the used scale can influence the results of models developed to explain the relationship between built environment and health (Cebrecos et al., 2018). The level of detail arises the debate between the use of individual and ecological models (Roux, 2001). The results for the civil parish are only a layer from the ecological model and can be substantially different to the individual's context when considering the individual biological and psychological characteristics (Roux, 2001).

The present paper confirms the relationship between built environment and several aspects of health pointed in other studies in Lisbon and in Portugal (Loureiro et al., 2019; Santana et al., 2015). Additionally, it confirms the influence of the built environment on physical activity levels (Pereira et al., 2018; Santana et al., 2009) specially the mediation role of active travel to the health outcome for the Portuguese context (Saelens et al., 2014; Van Cauwenberg et al., 2016). This paper tries to go further by including the several previous conclusions and exploring the relationships in a more complex approach reflecting the complexity of the relations between health and the built environment.

The results of the paper reinforce the role of primary healthcare facilities as a first level of response to control diabetes and promote health (Biscaia and Heleno, 2017). The results show that the distance increase from these primary healthcare facilities increases the number of hospital admissions due to diabetes, reinforcing the importance of improving accessibility and services available at these same facilities (Vaz et al., 2014). A future research should be focused on the local surrounding of these primary healthcare facilities and their contribution to an overall better health.

Unfortunately, the civil parish scale of analysis can have important limitations on results, but other limitations should also be acknowledged. First, our data are only for public hospitals. Further studies should also include data for private hospitals, because it is known that there is a link between socioeconomic status and the use of different healthcare facilities (Yu et al., 2017).

Moreover, hospital admissions due to diabetes do not reflect an effective diagnosis of diabetes neither a total prevalence of diabetes. Instead, it counts emergency episodes related to diabetes. Additionality, it is expected that the control of diabetes should be made at primary healthcare facilities, and the higher use of the hospital to treat diabetes can reflect an individual difficulty in controlling diabetes or a lack of access to these primary healthcare facilities (Vaz et al., 2014). Finally, the paper does not evaluate the true physical activity that can have many other forms beyond active travel. Furthermore, this different level of physical activity has an important role in obesity that we have not considered in our paper (Sallis et al., 2012, 2004). In a conceptual model focused on diabetes, it is crucial to consider obesity; in fact, obesity is one of the major consequences of insufficient levels of physical activity, increasing the risk of several diseases (Ewing et al., 2014). Several studies found a relationship between the built environment, physical activity, and obesity at different geographical scales and found that, at the city scale, the built environment, such as residential density, mix land use, and street network characteristics, has a strong impact on BMI (Body Mass Index) levels of populations (Sun and Yin, 2018; Yang and French, 2013). Unfortunately, the data about obesity is not available, and further studies that test the suggested model should consider obesity information to explain diabetes.

9. Conclusion

The study brings important insights for the research field of urban planning and health. First, to the best of our knowledge, it is the first study in Portugal focusing on the relevance of the built environment on hospital admissions for diabetes, confirming the importance of the built environment as a health determinant in Lisbon. Second, it reinforces the importance of built environment characteristics to explain hospital admissions, specially the role of active travel and air pollution. Jobs distribution is particularly important to influence the use of active travel, even more than the availability of public transport. The results point to the importance and contribution of the primary healthcare facilities as a first response to control diabetes and the important role they have at a proximity level. The importance of primary healthcare facilities reinforce the necessity of increasing the cover area of these facilities in the Lisbon Metropolitan Area (Biscaia and Heleno, 2017; Vaz et al., 2014).

For urban planning, the results reinforce the importance of looking to the population's health through built environment from a strategic perspective and different multilevel scales, bringing the discussion of health beyond mortality and morbidity, already explored at a regional and municipal scale. A strategic approach using an ecological model can sustain the definition of interventions on built environment and policies at different levels, which support the use of active modes of transportation and reveals the importance of multiscale approaches to a healthier and more sustainable living. The land use planning, with the distribution of activities and jobs, is crucial to a more active travel use. The promotion of active modes of transportation, public transport included, is a result of several levels of approach on changing behaviour.

This paper suggests a conceptual model to explain diabetes for one level of the complex multilevel model of health. This can be a starting point for modelling results on diabetes, introducing other levels of analysis, based on the influences established in this paper and the proposed model. The civil parish scale is a very wide scale with significant built environment and socioeconomic status variations, which makes it impossible to predict individual results. However, this paper can give an important contribution to the process of modelling the relationship between diabetes results and built environment. The results of the paper suggest developments of the most used walkability index, indicating the introduction of jobs density, due to its influence on active travel. The analysis and results can be improved, in the future, with the introduction of more detailed and individual characteristics and behaviours, including levels of physical activity, food habits, obesity, and social support mechanisms, crucial for results on diabetes (Smalls et al., 2014). Moreover, the proposed model assesses total population, particularly, active population, evaluating active travels for commuting trips. Population groups, such as the retired population who do not normally commute and who are more dependent on primary healthcare facilities, can have different influences on active travel as in the rest of the variables considered in the model, consequently, further research is suggested.

Author statement

Mauro F. Pereira: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Funding acquisition.

Ricardo Almendra: Conceptualization, Methodology, Writing - Review & Editing, Resource.

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Appendix A

Table 4
Types of activities.

Types of activities	Description
Retail	gas stations, hotels, clothes shops, hair salons; pharmacies
Entertainment	Theatres, museums, auditoriums, churches
Civic and institutional	Schools, Post offices, city hall, police, law court
Food-related	supermarket, groceries, restaurants, coffee shops
Office	Services, lawyers, architects, officers
Recreation	Parks, beaches, swimming pools, gyms, stadiums

Appendix B

Table 5
List of considered hospitals in accessibility measures.

Hosp. Dis. Torres Vedras
Hospital Curry Cabral
Hospital Da C. V. P.
Hospital De Egas Moniz
Hospital de Loures
Hospital De Santa Maria
Hospital de Vila Franca
Hospital Desterro
Hospital Dona Estefânia
Hospital Dr. José Almeida
Hospital Fernando Fonseca
Hospital Garcia De Orta
Hospital Montijo
Hospital N. Sra. Rosário
Hospital S. Franc. Xavier
Hospital Santa Marta
Hospital São Bernardo
Hospital São José
I. P. O. F. Gentil

Appendix C

Table 6
Pearson's correlations of weighted variables.

Pearson Correlation		var1	var2	var3	var4	var5	var6	var7	var8	var9	var10	var11	var12	var13	var14	var15	var16	var17	var18	var19	Var20	var21	var22	var23	var24
SqrHouse NoToilet	**var1**	1																							
High Education	**var2**	-.401**	1																						
Average Age	**var3**	-.034**	.353**	1																					
Illiteracy	**var4**	**.629****	**-.546****	.057**	1																				
Employment	**var5**	.167**	**-.656****	-.060**	.484**	1																			
Material Deprivation	**var6**	**.657****	**-.688****	-.010**	**.884****	**.775****	1																		
HouseArea	**var7**	0.001	.402**	.229**	.297**	**-.596****	.447**	1																	
HouseCost	**var8**	**.052****	**.600****	.164**	.154**	**-.581****	.353**	**.617****	1																
Crowded Household	**var9**	-.023**	**-.537****	-.246**	.293**	**.638****	.466**	**-.726****	**-.507****	1															
OnePersons Household	**var10**	.167**	.476**	**.859****	.130**	.063**	.129**	.398**	.104**	.086**	1														
Walkability Index	**var11**	**-.501****	.466**	.461**	-.379**	-.087**	-.346**	-.318**	.011**	.057**	**.663****	1													
Activities Variety	**var12**	-.361**	.349**	.233**	-.321**	-.080**	-.297**	-.011**	.114**	-.125**	.309**	**.598****	1												
SqrComercial Density	**var13**	-.377**	**.552****	**.536****	-.314**	-.205**	-.337**	-.175**	.203**	-.062**	**.697****	**.817****	.369**	1											
Srq Connectivity	**var14**	-.474**	.378**	.325**	-.350**	-.058**	-.302**	-.335**	-.072**	.118**	.518**	**.798****	.179**	**.704****	1										
Residential Density	**var15**	-.356**	.303**	.425**	-.242**	-.017**	-.203**	-.425**	-.102**	.179**	**.630****	**.831****	.110**	**.733****	**.752****	1									
SrqJobs Density	**var16**	-.372**	**.590****	.445**	-.285**	-.257**	-.352**	-.148**	.213**	-.072**	**.620****	**.763****	.353**	**.904****	**.679****	**.680****	1								
Log10Green_ PerCapita	**var17**	.374**	.070**	.010**	.248**	.127**	.134**	.328**	.263**	.262**	.198**	.461**	0.001	.411**	**-.598****	**-.553****	.401**	1							
AirPollution	**var18**	.463**	**.502****	.387**	.247**	.118**	.289**	.344**	.019**	.106**	**.561****	**.709****	.200**	**.713****	**.803****	**.698****	**.732****	**-.503****	1						
Commuting Time	**var19**	-.074**	-.492**	-.324**	-.091**	.414**	.152**	-.148**	-.478**	.287**	-.344**	-.248**	-.229**	-.396**	-.056**	-.155**	-.459**	-.090**	-.236**	1					
TravelTime_ Hospital	**var20**	.291**	.287**	.313**	.168**	.152**	.084**	.318**	.106**	.072**	.458**	**-.507****	.281**	.463**	.450**	.437**	.438**	.337**	**-.510****	.188**	1				
Log10_Travel TimePHCF	**var21**	.382**	-.105**	-.163**	.319**	-.188**	.168**	.349**	.301**	-.150**	-.315**	-.416**	-.245**	-.212**	-.452**	-.353**	-.238**	.358**	-.378**	-.132**	.419**	1			
Public Transport	**var22**	-.324**	**.581****	.435**	-.129**	-.234**	-.259**	-.153**	.221**	-.082**	**.552****	**.559****	.423**	**.615****	.472**	.388**	**.672****	-.180**	**.699****	-.472**	-.375**	-.146**	1		
ActiveTravel	**var23**	-.094**	-.301**	.308**	.173**	**.610****	.370**	**-.829****	**-.594****	**.564****	.444**	.436**	.038**	.385**	.461**	**.536****	.314**	-.409**	.444**	.259**	-.381**	-.369**	.245**	1	
TIP_Diabetes	**var24**	.138**	-.270**	-.155**	.199**	.195**	.226**	-.222**	-.157**	.354**	-.129**	-.101**	.005**	-.186**	-.180**	-.102**	-.196**	.080**	-.193**	.022**	-.087**	-.002**	-.124**	.058**	1

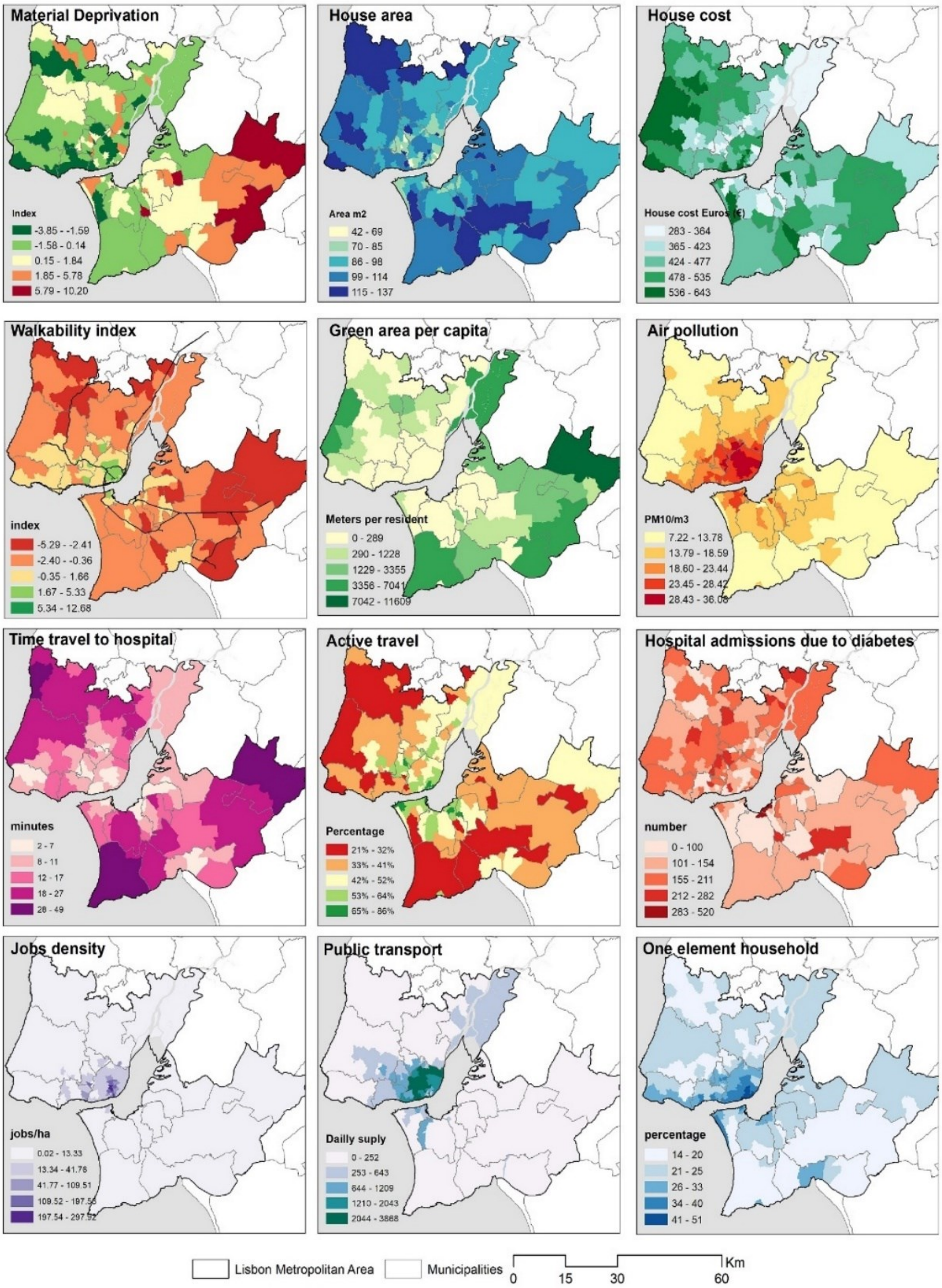
** Correlation is significant at the 0.01 level (2-tailed).
In bold de values with strong correlations greater than 0.50.
Underlined the values with very strong correlations greater than 0.75.

Appendix D

Table 7
Estimates of covariances among exogenous weighted variables.

			Estimate	S.E.	p	β
walkability_index	<–>	SrqJobsDensity	3.058	0.003	***	0.763
SrqJobsDensity	<–>	AirPollution	11.453	0.012	***	0.732
walkability_index	<–>	AirPollution	6.959	0.007	***	0.709
PublicTransport	<–>	AirPollution	3549.808	3.688	***	0.699
PublicTransport	<–>	SrqJobsDensity	1394.201	1.488	***	0.672
walkability_index	<–>	OnePersonsHousehold	8.141	0.009	***	0.663
SrqJobsDensity	<–>	OnePersonsHousehold	12.137	0.014	***	0.620
ActiveTravel	<–>	CrowdedHousehold	23.835	0.029	***	0.564
AirPollution	<–>	OnePersonsHousehold	26.874	0.033	***	0.561
walkability_index	<–>	PublicTransport	728.227	0.888	***	0.559
PublicTransport	<–>	OnePersonsHousehold	3509.556	4.323	***	0.552
MaterialDeprivation	<–>	CrowdedHousehold	2.982	0.004	***	0.466
ActiveTravel	<–>	AirPollution	30.260	0.044	***	0.444
ActiveTravel	<–>	OnePersonsHousehold	37.929	0.056	***	0.444
ActiveTravel	<–>	walkability_index	7.615	0.011	***	0.436
TravelTime_Hospital	<–>	Log10_TravelTimeCS	0.430	0.001	***	0.419
ActiveTravel	<–>	MaterialDeprivation	6.807	0.012	***	0.370
Log10_GreenPerCapita	<–>	Log10_TravelTimeCS	0.065	0.000	***	0.358
HouseArea	<–>	Log10_TravelTimeCS	0.861	0.002	***	0.349
Log10_GreenPerCapita	<–>	TravelTime_Hospital	1.940	0.004	***	0.337
Log10_GreenPerCapita	<–>	HouseArea	4.548	0.009	***	0.328
HouseArea	<–>	TravelTime_Hospital	25.012	0.049	***	0.318
ActiveTravel	<–>	SrqJobsDensity	8.744	0.017	***	0.314
ActiveTravel	<–>	PublicTransport	2218.967	5.547	***	0.245
MaterialDeprivation	<–>	Log10_TravelTimeCS	0.050	0.000	***	0.168
MaterialDeprivation	<–>	Log10_GreenPerCapita	0.226	0.001	***	0.134
CrowdedHousehold	<–>	AirPollution	2.516	0.014	***	0.106
MaterialDeprivation	<–>	TravelTime_Hospital	0.807	0.006	***	0.084
walkability_index	<–>	CrowdedHousehold	0.348	0.004	***	0.057
CrowdedHousehold	<–>	SrqJobsDensity	-0.700	0.006	***	-0.072
CrowdedHousehold	<–>	TravelTime_Hospital	-1.582	0.013	***	-0.072
CrowdedHousehold	<–>	PublicTransport	-257.345	1.879	***	-0.082
CrowdedHousehold	<–>	OnePersonsHousehold	-2.555	0.018	***	-0.086
MaterialDeprivation	<–>	OnePersonsHousehold	-1.663	0.008	***	-0.129
PublicTransport	<–>	Log10_TravelTimeCS	-21.458	0.088	***	-0.146
HouseArea	<–>	SrqJobsDensity	-5.148	0.021	***	-0.148
CrowdedHousehold	<–>	Log10_TravelTimeCS	-0.103	0.000	***	-0.150
HouseArea	<–>	PublicTransport	-1731.800	6.807	***	-0.153
Log10_GreenPerCapita	<–>	PublicTransport	-149.231	0.500	***	-0.180
Log10_GreenPerCapita	<–>	OnePersonsHousehold	-1.542	0.005	***	-0.198
SrqJobsDensity	<–>	Log10_TravelTimeCS	-0.108	0.000	***	-0.238
MaterialDeprivation	<–>	PublicTransport	-354.358	0.843	***	-0.259
Log10_GreenPerCapita	<–>	CrowdedHousehold	-1.012	0.002	***	-0.262
MaterialDeprivation	<–>	AirPollution	-2.985	0.006	***	-0.289
Log10_TravelTimeCS	<–>	OnePersonsHousehold	-0.436	0.001	***	-0.315
walkability_index	<–>	HouseArea	-6.951	0.014	***	-0.318
HouseArea	<–>	AirPollution	-29.311	0.054	***	-0.344
MaterialDeprivation	<–>	walkability_index	-0.916	0.002	***	-0.346
MaterialDeprivation	<–>	SrqJobsDensity	-1.484	0.003	***	-0.352
ActiveTravel	<–>	Log10_TravelTimeCS	-0.729	0.001	***	-0.369
PublicTransport	<–>	TravelTime_Hospital	-1762.545	2.986	***	-0.375
Log10_TravelTimeCS	<–>	AirPollution	-0.419	0.001	***	-0.378
ActiveTravel	<–>	TravelTime_Hospital	-24.020	0.040	***	-0.381
HouseArea	<–>	OnePersonsHousehold	-42.399	0.068	***	-0.398
Log10_GreenPerCapita	<–>	SrqJobsDensity	-1.022	0.002	***	-0.401
ActiveTravel	<–>	Log10_GreenPerCapita	-4.547	0.007	***	-0.409
walkability_index	<–>	Log10_TravelTimeCS	-0.118	0.000	***	-0.416
SrqJobsDensity	<–>	TravelTime_Hospital	-6.340	0.009	***	-0.438
MaterialDeprivation	<–>	HouseArea	-10.265	0.015	***	-0.447
TravelTime_Hospital	<–>	OnePersonsHousehold	-20.285	0.029	***	-0.458
Log10_GreenPerCapita	<–>	walkability_index	-0.737	0.001	***	-0.461
Log10_GreenPerCapita	<–>	AirPollution	-3.133	0.004	***	-0.503
walkability_index	<–>	TravelTime_Hospital	-4.597	0.006	***	-0.507
TravelTime_Hospital	<–>	AirPollution	-18.057	0.024	***	-0.510
HouseArea	<–>	CrowdedHousehold	-38.301	0.039	***	-0.726
ActiveTravel	<–>	HouseArea	-125.895	0.117	***	-0.829

Appendix E


Material Deprivation
Index
-3.85 - -1.59
-1.58 - 0.14
0.15 - 1.84
1.85 - 5.78
5.79 - 10.20
House area
Area m2
42 - 69
70 - 85
86 - 98
99 - 114
115 - 137
House cost
House cost Euros (€)
283 - 364
365 - 423
424 - 477
478 - 535
536 - 643
Walkability index
index
-5.29 - -2.41
-2.40 - -0.36
-0.35 - 1.66
1.67 - 5.33
5.34 - 12.68
Green area per capita
Meters per resident
0 - 289
290 - 1228
1229 - 3355
3356 - 7041
7042 - 11609
Air pollution
PM10/m3
7.22 - 13.78
13.79 - 18.59
18.60 - 23.44
23.45 - 28.42
28.43 - 36.08
Time travel to hospital
minutes
2 - 7
8 - 11
12 - 17
18 - 27
28 - 49
Active travel
Percentage
21% - 32%
33% - 41%
42% - 52%
53% - 64%
65% - 86%
Hospital admissions due to diabetes
number
0 - 100
101 - 154
155 - 211
212 - 282
283 - 520
Jobs density
jobs/ha
0.02 - 13.33
13.34 - 41.76
41.77 - 109.51
109.52 - 197.53
197.54 - 297.92
Public transport
Dailly suply
0 - 252
253 - 643
644 - 1209
1210 - 2043
2044 - 3868
One element household
percentage
14 - 20
21 - 25
26 - 33
34 - 40
41 - 51
Lisbon Metropolitan Area
Municipalities
0
15
30
60
Km

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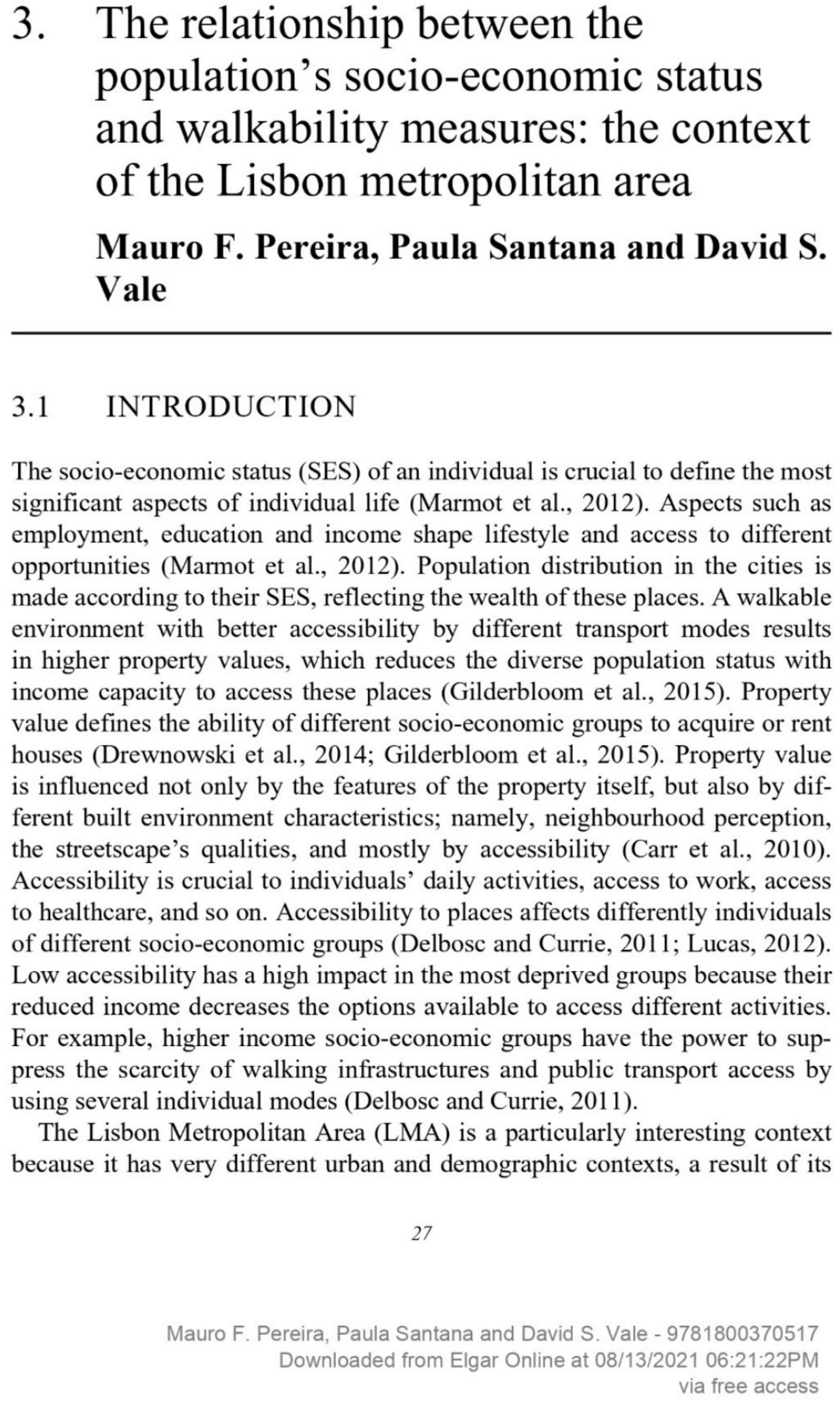
5.3 III. The relationship between the population's socio-economic status and walkability measures: the context of the Lisbon metropolitan area



3. The relationship between the population's socio-economic status and walkability measures: the context of the Lisbon metropolitan area

Mauro F. Pereira, Paula Santana and David S. Vale

3.1 INTRODUCTION

The socio-economic status (SES) of an individual is crucial to define the most significant aspects of individual life (Marmot et al., 2012). Aspects such as employment, education and income shape lifestyle and access to different opportunities (Marmot et al., 2012). Population distribution in the cities is made according to their SES, reflecting the wealth of these places. A walkable environment with better accessibility by different transport modes results in higher property values, which reduces the diverse population status with income capacity to access these places (Gilderbloom et al., 2015). Property value defines the ability of different socio-economic groups to acquire or rent houses (Drewnowski et al., 2014; Gilderbloom et al., 2015). Property value is influenced not only by the features of the property itself, but also by different built environment characteristics; namely, neighbourhood perception, the streetscape's qualities, and mostly by accessibility (Carr et al., 2010). Accessibility is crucial to individuals' daily activities, access to work, access to healthcare, and so on. Accessibility to places affects differently individuals of different socio-economic groups (Delbosc and Currie, 2011; Lucas, 2012). Low accessibility has a high impact in the most deprived groups because their reduced income decreases the options available to access different activities. For example, higher income socio-economic groups have the power to suppress the scarcity of walking infrastructures and public transport access by using several individual modes (Delbosc and Currie, 2011).

The Lisbon Metropolitan Area (LMA) is a particularly interesting context because it has very different urban and demographic contexts, a result of its dimension and changes across time. However, there is little knowledge about the relationship between socio-economic groups' distribution and walkable characteristics. The goal of the chapter is to understand the distribution and relationship between walkable characteristics and socio-economic groups across the LMA, distinguishing areas according to their travel time to the city centre. To achieve this goal, different indicators used to measure walkability were tested and correlated with SES indicators.

3.2 BACKGROUND

Health and wellbeing determinants define an ecological model where individual characteristics are in the centre of this model, but context spheres also influence individual health and wellbeing (Barton and Grant, 2006). Individual socio-demographics play a crucial role in health and wellbeing. However, the sphere of closer context at the level of the bespoke neighbourhood had influences on these individual characteristics, allowing healthier lifestyles. The spatial built environment characteristics define the access level of different opportunities and where transport options are crucial to access these opportunities (Geurs and van Wee, 2004). Transport options have different costs, and different socio-economic groups have distinct resources to face these costs (Delbosc and Currie, 2011). A walkable environment with a walkable distance to the most important daily activities is the cheapest option and it reduces the need for longer distance trips. Moreover, it is well known that a walkable place has impact on other health determinants, such as physical activity and social interaction, that increase wellbeing (Loureiro et al., 2019).

Most previous studies about the relationship between walkable environment and socio-economic status were performed in the North American and Australian contexts, where the spatial distribution of socio-economic groups is stronger (Gullón et al., 2017). The European context has different development patterns with different spatial reasons to shape population distribution (Munoz, 2003). The Portuguese context, in this case, the LMA, shares these different developments where different socio-economic groups occupy different built environment characteristics across the city, with different levels of accessibility (Santana, 2007).

The design of a walkable environment that supports the use of active and public transport modes to the most important destinations allows the reduction of inequalities, promoting access by inexpensive modes of transportation (Badland et al., 2014; Giles-Corti et al., 2016). A built environment that promotes walking and cycling helps to reduce inequities and can benefit such aspects as health, traffic management, air quality and economy. Urban areas that reduce the need of mandatory transportation far from walkable distances can improve individual wellbeing and living conditions (Giles-Corti et al., 2016). Unfortunately, disadvantaged populations face disparities on walkability, safety and health, and also inequities in facilities and built environment conditions. The benefits of walking are especially important for disadvantaged groups and they have a higher cost for disadvantaged and vulnerable populations (Adkins et al., 2017). The identification of less walkable areas can improve the design of policy and planning interventions (King and Clarke, 2015).

A walkable built environment refers to how favourable the built environment is for walking, and it can be used to improve physical activity and active travel. Walkability is commonly defended as a measure which defines whether the existing neighbourhood qualities encourage people to walk (Wang and Yang, 2019). The most used walkability indexes are composed of such built environment dimensions as residential density, intersection density, the retail floor area ratio and land use mix. The indicators follow three main categories ('three Ds'): density, diversity and design as determinants of walking. Later, these were expanded to 'five Ds' to include destination accessibility and distance to transit (Ewing and Cervero, 2010), which some authors claim can be conceived not as pure built environment but as (dependent) accessibility indicators, reframing the 'five Ds' as '3 Ds + A' (Vale and Pereira, 2016).

Pedestrian accessibility conditions of the residential neighbourhood define several aspects of daily life with impacts on wellbeing (Delbosc and Currie, 2011). One of these aspects is time spent on travelling, which reduces the free time available for other important activities, such as social interactions, family time and leisure (Lachapelle et al., 2016). In addition, the absence of free time is one of the major determinants of reduced social interaction. This shortage of free time is called 'time poverty', and can contribute to increase social exclusion and to reduce subjective wellbeing (Currie and Delbosc, 2010). Public transport accessibility is especially important for the disadvantaged population, more dependent on these mobility options (Lucas, 2012).

Urban green areas contribute to wellbeing by improving social interaction and integration (Picavet et al., 2016; Ward Thompson et al., 2016). Some interesting facts are the different effects on mental health and stress levels that urban green areas have in different socio-economic groups, and also the contribution of urban green areas to reducing economic health inequalities (Ward Thompson et al., 2016). A consensual result in the literature highlights the effects of urban green areas on health, not only in terms of physical activity but also in terms of mental health (Douglas et al., 2017; Loureiro et al., 2019; Picavet et al., 2016). Moreover, proximity to green areas is considered relevant for a walkable environment and contributes to better living conditions and healthy environments (Picavet et al., 2016). The contribution of green area accessibility to wellbeing is supported by literature which points to the influence on individual behaviours such as physical activity and social interaction.

A walkable environment has been shown to influence property value (Carr et al., 2010). One of the most used walkability indicators, the Walk Score®, has been used to evaluate house prices, reflecting the impact of walkability on increasing this price and, consequently, influencing the socio-economic groups' location (Carr et al., 2010; Vale et al., 2016).

Property value has been used as a measure of socio-economic characteristics (Drewnowski et al., 2014; Jiao et al., 2016), due to the role of property value to conditionate the type of SES present in a place. Property value emphasizes the perception of poverty or wealth of a place. The individuals' perception of the surrounding built environment has an impact in their own view of SES, but it also has an impact on property values (Drewnowski et al., 2014). These aspects reinforce the impact of the built environment to the spatial distribution of different socio-economic groups, with property value being a condition for housing access. Accessibility to the city centre shapes individuals' home location, which results from the competition between several activities. The higher property values in the city centre exclude the most deprived population, yet the sprawl effects in modern development create settlements of higher SES far from the city centre (Koschinsky and Talen, 2015). Nevertheless, the distribution of population differs from city to city, and the occupation of a particular place by different socio-economic groups can change through time (Gullón et al., 2017). Furthermore, the spatial distribution of these places across countries and cities is not equal, and it is not always representative of the population status present in these places.

3.3 METHODOLOGY

3.3.1 Study Area and Design

The LMA is a regional administrative division composed of 18 municipalities and 211 civil parishes (34 937 census blocks). The LMA represents 3.3 per cent of the total area of Portugal, with approximately 3 million inhabitants (25 per cent of the Portuguese population). In economic terms, it represents more than 36 per cent of the national gross domestic product. The built environment was measured considering the walkability concept, including accessibility measures and topography conditions. The SES evaluation uses indicators of population wealth.

The relationship between walkability and SES was evaluated by a Spearman correlation matrix. Due to different urban and demographic contexts existent in LMA, four groups of census tracts were created considering 15 minutes, 30 minutes, 45 minutes and more than 45 minutes morning peak travel times from city centre (see Figure 3.1c in the 'Results' section). Travel time was calculated for car mode considering traffic information. The selection of 15 minutes groups was supported by the impact of the commuting time for wellbeing, which is one of the major reasons for travel mode selection (Delbosc and Currie, 2011; Giles-Corti et al., 2016). Linear regression was performed for each group separately. We have analysed relationships between SES and walkability indicators and for the two indexes created.

3.3.2 SES Measures

The most common SES indexes use indicators such as income, education or occupation (Cebrecos et al., 2018; Santana et al., 2015). However, property value is important in shaping several aspects of health and wellbeing (Drewnowski et al., 2014; Jiao et al., 2016). In this chapter, we calculated an SES index that is composed of four indicators: (1) literacy rate; (2) employment rate; (3) percentage of households with a toilet; and (4) property value (€/m^2). The indicators were standardized, and the z-scores were summed to form the composite SES index (Santana et al., 2015):

$$\text{SES Index} = \text{z-score LiteracyRate} + \text{z-score EmploymentRate} + \text{z-scoreHouseWithToilet} + \text{z-score PropertyValue} \quad (3.1)$$

Property value (euros/m^2) was obtained from a retail housing website (www.imovirtual.com), collecting the coordinates of the real estate property for sale in November 2018. Based on the asking price and dimensions of the house, the price per square metre was calculated for each point. The points obtained were used to interpolate a surface using Empirical Bayesian Kriging available in ArcGIS 10.6 and predicting the property value to the census block centroids (euros/m^2). The results for census block were then aggregated at census tract with an average value. The source of the remaining SES indicators is the 2011 census data aggregated at census tracts.

3.3.3 Walkability Measure

Walkability was measured for a 500 m buffer around each urban census block. The indicators were then aggregated at the census tract to better describe the bespoke neighbourhood and to control the modifiable area unit problem (Openshaw, 1983). We have calculated a walkability index in line with the most used walkability indexes (Wang and Yang, 2019), including density, diversity and design, but also comprising accessibility measures and topography conditions. Density was measured by household density based on the 2011 census data. Diversity was measured by the number of different types of activities obtained from points of interest information (POIs) from the Navteq[1] database. The design dimension was measured by density of road intersections (nodes) with three or more links, also from the Navteq database. Topography was evaluated by the percentage of census block with a slope less than 8 per cent, calculated based on a digital terrain model raster with 30 metres resolution. Accessibility measures evaluate the accessibility to green areas and public transport accessibility. The green areas considered were 'green urban areas' and 'forests' classification in Urban Atlas (Kabisch and Haase, 2014). Two green areas indicators were created: the percentage of the buffer area occupied by green area and the total of green area in the census block.

Public transport accessibility was measured following Currie and Delbosc's (2010) methodology, adapted to the LMA context by considering station buffers sizes of 400m to bus, 800m to train, 500m to tram and 800m to ferryboat. The public transport index consists of daily transport supply in each walking buffer, which is calculated by the proportion of overlapped buffers in the census tract. The calculation was performed with BetterBusBuffers, an ArcGIS tool based on a General Transit Feed Specification (GTFS) database available at the city's open data portal.[2] The final walkability index is given by the formula:

$$\text{Walkability Index} = \text{z-score Density} + \text{z-score Diversity} + \text{z-score Design} + \text{z-score Green Area} + \text{z-score Slope} + \text{z-score PT Accessibility} \quad (3.2)$$

3.4 RESULTS

Figure 3.1 illustrates the spatial pattern of the SES and walkability index. The SES index does not reveal a clear pattern, having high and low values in the four census tract groups. The SES map highlights the spatial pattern of property values, particularly clear for Lisbon's city centre and coastal line, which have higher property values. In the case of the walkability index, a clear distinction is visible between Lisbon's city centre and the rest of the LMA. The 15 minutes census tract group and Lisbon municipality have the highest walkability index values. The walkability index emphasizes the city centre with the highest public transport offer, but also highlights the census tracts further from the city centre, which have lower accessibility but possess higher levels of green areas and higher percentages of low slope area.

The results of the Spearman correlation (Figure 3.2) show no association between socio-economic indicators and walkability indicators (grey box). Property value is the socio-economic indicator with the highest correlation values with walkability indicators. Particularly, accessibility to public transport shows a significant relation with property value, although the value is small (0.53). The variety dimension (0.48) and walkability index (0.46) are also significantly related to property values, but with lower coefficients. The

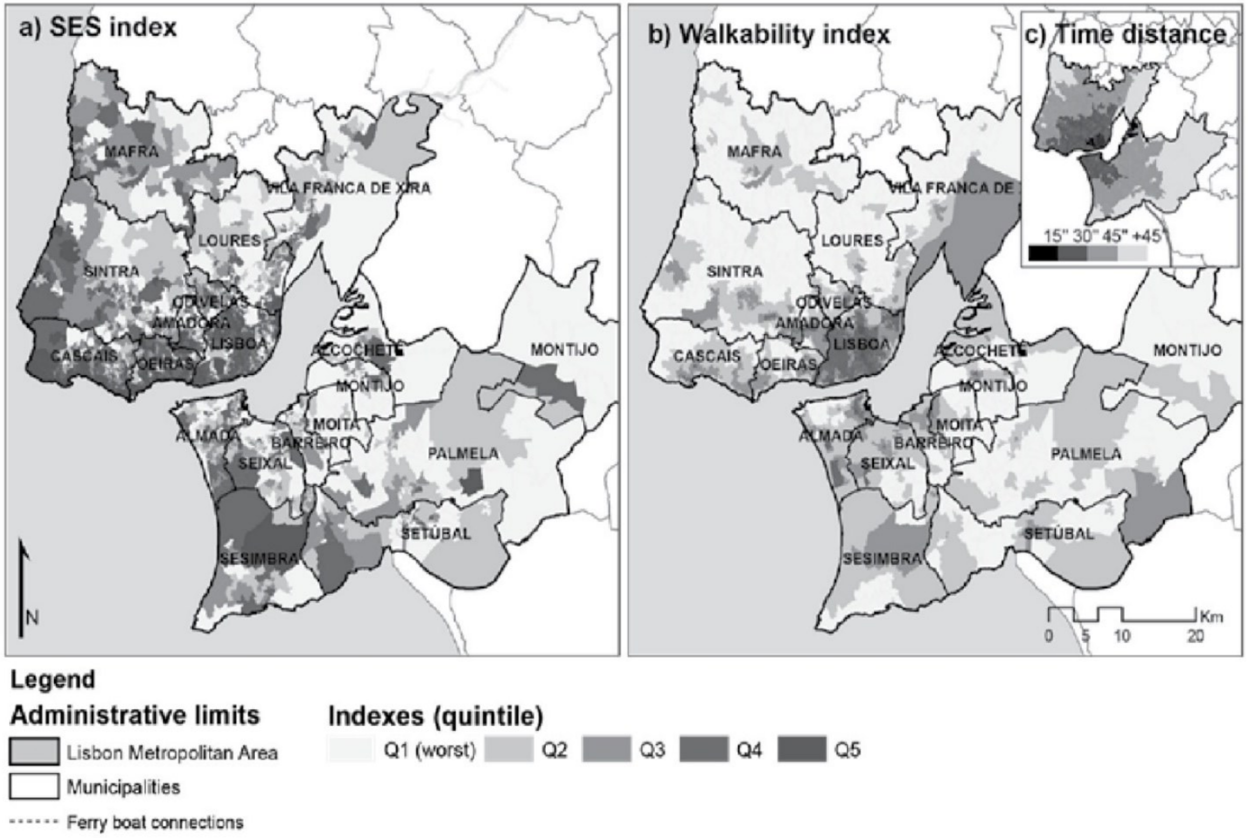
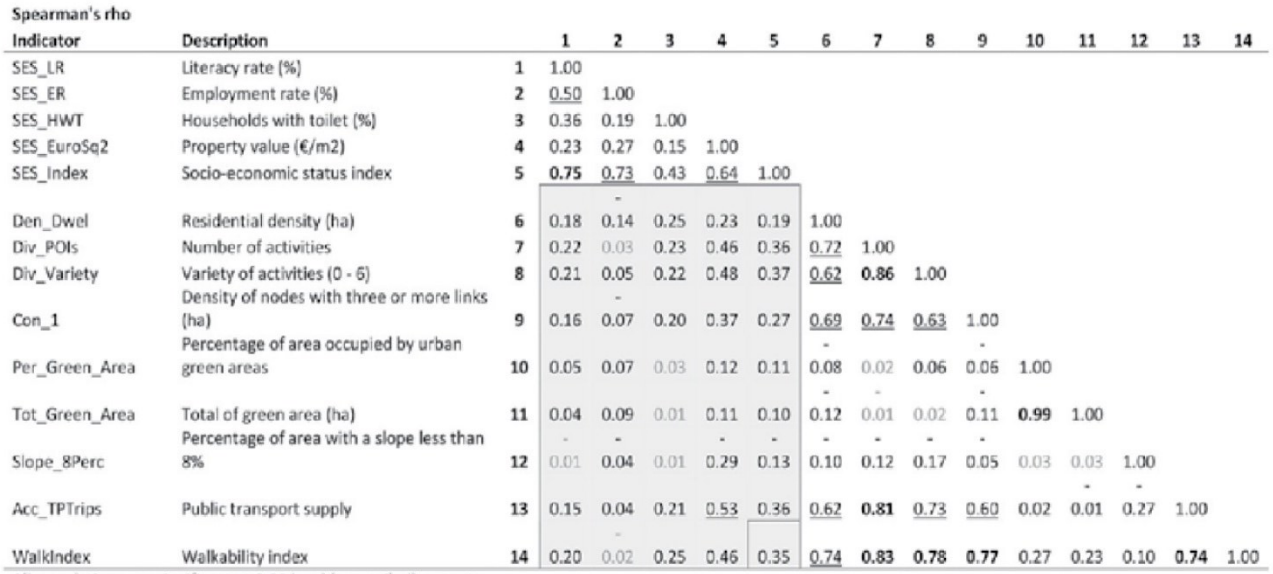


Figure 3.1 *a) SES index map; b) Walkability index map; c) Time distance to city centre*



Spearman's rho

Indicator	Description		1	2	3	4	5	6	7	8	9	10	11	12	13	14
SES_LR	Literacy rate (%)	**1**	1.00													
SES_ER	Employment rate (%)	**2**	0.50	1.00												
SES_HWT	Households with toilet (%)	**3**	0.36	0.19	1.00											
SES_EuroSq2	Property value (€/m2)	**4**	0.23	0.27	0.15	1.00										
SES_Index	Socio-economic status index	**5**	**0.75**	0.73	0.43	0.64	1.00									
Den_Dwel	Residential density (ha)	**6**	0.18	-0.14	0.25	0.23	0.19	1.00								
Div_POIs	Number of activities	**7**	0.22	0.03	0.23	0.46	0.36	0.72	1.00							
Div_Variety	Variety of activities (0 - 6)	**8**	0.21	0.05	0.22	0.48	0.37	0.62	**0.86**	1.00						
Con_1	Density of nodes with three or more links (ha)	**9**	0.16	-0.07	0.20	0.37	0.27	0.69	0.74	0.63	1.00					
Per_Green_Area	Percentage of area occupied by urban green areas	**10**	0.05	0.07	0.03	0.12	0.11	-0.08	0.02	0.06	-0.06	1.00				
Tot_Green_Area	Total of green area (ha)	**11**	0.04	0.09	0.01	0.11	0.10	-0.12	-0.01	0.02	-0.11	**0.99**	1.00			
Slope_8Perc	Percentage of area with a slope less than 8%	**12**	-0.01	-0.04	0.01	-0.29	-0.13	-0.10	-0.12	-0.17	-0.05	0.03	0.03	1.00		
Acc_TPTrips	Public transport supply	**13**	0.15	0.04	0.21	0.53	0.36	0.62	**0.81**	0.73	0.60	0.02	-0.01	-0.27	1.00	
WalkIndex	Walkability index	**14**	0.20	-0.02	0.25	0.46	0.35	0.74	**0.83**	**0.78**	**0.77**	0.27	0.23	0.10	**0.74**	1.00

All correlations are significant at 0.01 level (two-tailed), except the values in gray

Underlined - strong correlation values (0.50< x <0.75)

In bold - very strong correlation values (>0.75)

Figure 3.2 Spearman correlation matrix

highest values are observed between the different built environment indicators and the walkability index; for example, walkability index and variety of activities (0.86), and the walkability index and public transport supply (0.74).

Figure 3.3 consists of scatter plots which show the relationship between walkability indicators and socio-economic indicators for the four groups of census tracts considered. Considering the entire LMA, the highest regression value is between the walkability index and property value ($r^2 = 0.32$). The highest walkability indicator value correlated with the SES index is public transport supply ($r^2 = 0.13$), followed by diversity ($r^2=12$) and the walkability index ($r^2 = 0.12$). The results stress the importance of these components for the indexes created. The remaining walkability indicators do not reveal a correlation with the SES index.

Regression values for the four groups are low. However, the difference between the closest group, at 15 minutes from the city centre, and the rest of the LMA are clear. The highest correlation value is diversity ($r^2 = 0.16$) for the 15 minutes group, and the following group has a much lower correlation value ($r^2 = 0.03$). The following highest correlation is between the walkability index and property value for the 15 minutes group ($r^2 = 0.13$). In this case, the difference for the next group is lower ($r^2 = 0.11$). The slope and SES index have a high value for the 15 minutes group ($r^2 = 0.12$), but a very low value for the rest of the groups. The walkability index and the SES index have the following highest value for the 15 minutes group ($r^2 = 0.09$). For the next group, the difference is not as high ($r^2 = 0.05$). Public transport supply, green area and design have a similar behaviour for correlation values, stressing the difference between the closest census tracts and the rest of the city. The density indicator reveals a lack of correlation with the SES index for all the four groups.

3.5 CONCLUSIONS

This chapter has explored the relationship between the distribution of the walkable qualities across different socio-economic groups, considering the distance to the city centre where most of the facilities are concentrated. The description of the built environment by walkability measures defines most of the qualities of a human scale city. The analysis of distribution of the human scale city qualities by the type of population served by these qualities can point towards policies and interventions to improve wellbeing by creating a walkable environment.

We have found a low correlation between socio-economic indicators and walkable indicators. The results reveal a relationship between property value and accessibility by walking and also by public transport, in line with other studies (Carr et al., 2010; Koster and Rouwendal, 2012). Correlation values are significantly different between the closer groups and the rest of the LMA,

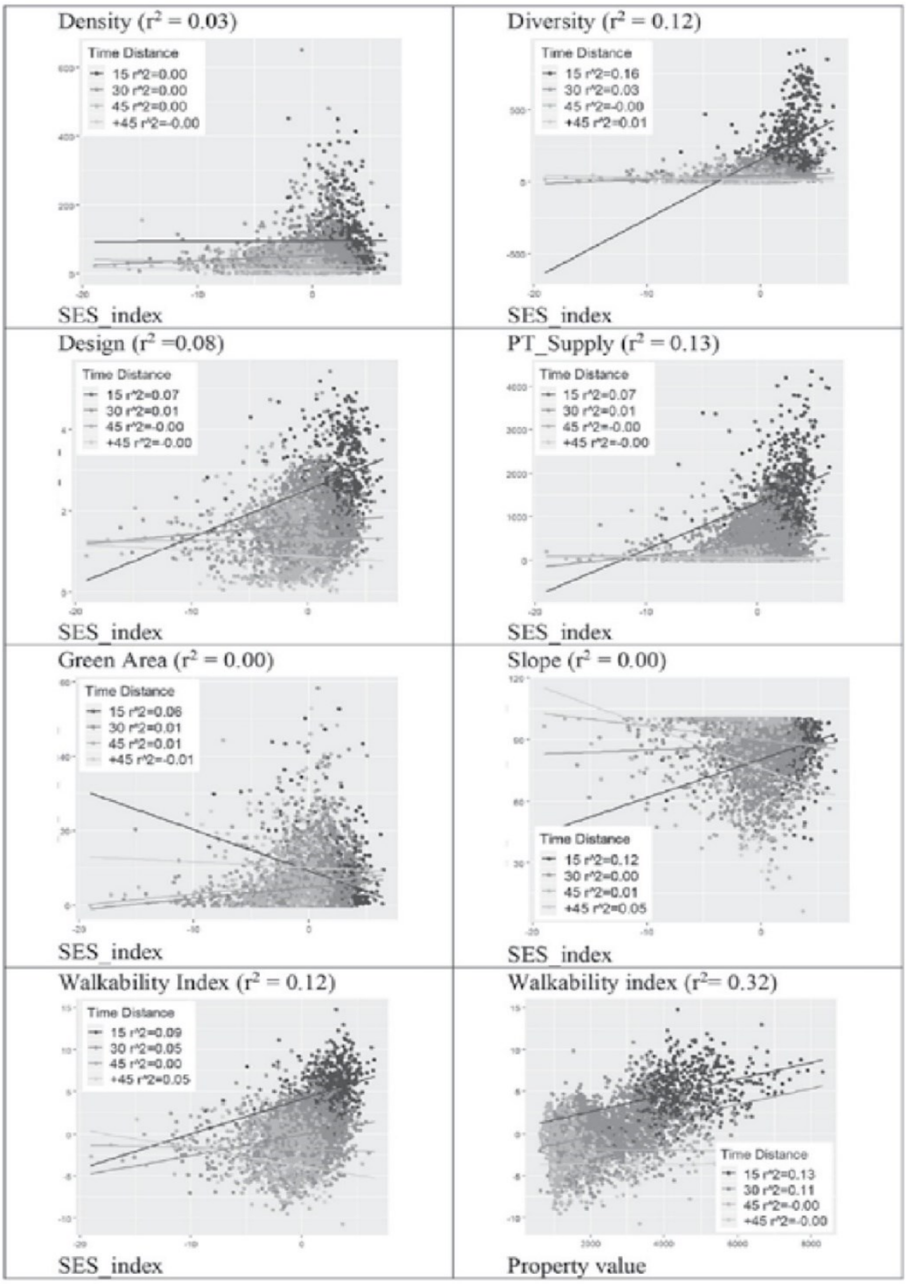


Figure 3.3 *Scatter plots for each walkability measure and SES index, by time distance to city centre*

especially for diversity of activities and public transport supply. The four groups remain with lower correlation values, but the closest group is significantly different. The highest correlation between the SES index and diversity identifies that the most central area is best served by public transport and activities. However, only 10 per cent of the LMA population lives within 15 minutes of the city centre. The major proportion of the population (63 per cent) lives in the second group (15 to 30 minutes) where a relatively good value of walkability was registered. The census tracts at more than 45 minutes from the city centre represent only 2 per cent of the LMA population, with the lowest walkability measures. The lower correlation and regression values between walkability and SES reveal that the most deprived people occupy places with different walkability qualities. Nonetheless, it seems that the city centre is mostly an exclusive area, occupied by the highest SES.

The results point to a relatively good distribution of the walkability qualities in the LMA, though an important distinction exists between the city centre and the rest of the LMA, especially in public transport supply and diversity of activities. Future studies should consider time distance to the centre in other modes, and different census tract groups should be tested. The chapter is a starting point to evaluate the distribution of walkability qualities in the LMA, pointing to the most human scale parts of the city that can contribute to better social inclusion.

NOTES

1. See https://www.here.com/navteq.
2. See http://lisboaaberta.cm-lisboa.pt/index.php/pt.

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5.4 IV. *Is walkability equitably distributed across socio-economic groups? – A spatial analysis for Lisbon Metropolitan Area.*

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Is walkability equitably distributed across socio-economic groups? – A spatial analysis for Lisbon metropolitan area

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ABSTRACT

The development of sustainable and equitable cities is on most international and national agendas – and the promotion of a walkable environment is crucial for sustainable development. Although it seems plausible to assume that walkable environments are not always equally distributed among socio-economic groups in dense metropolitan areas, we lack empirical knowledge. This paper, therefore, evaluates the relationship between the socio-economic characteristics of the population of the Lisbon Metropolitan Area (Portugal) and the distribution of walkable environments, focusing exclusively on the urban part of the metropolitan area.

Walkability was captured by design, diversity and density indicators, together with access to green areas and public transportation, and including slope. Inequity was measured using the Lorenz curve and Gini coefficient. An index based on a principal component analysis was created to describe socio-economic characteristics.

Our results reveal a spatial autocorrelation of all considered indicators. The SES indicators have a smaller Global Moran's I compared with the walkability indicators. At local level, walkability is associated with a higher degree of clustering, suggesting an unequal distribution. The most unequally-distributed indicator is public transport accessibility, which is crucial for household budgets and has a higher impact on low-income populations.

The evaluation of walkability and socio-economic status can be a useful guide for interventions that seek to provide walkable environments and prioritize the most deprived populations, and develop public policies that can reduce social and geographical inequity.

1. Introduction

The development of sustainable and equitable cities is a key objective of many international agendas (European Commission, 2014; Patel et al., 2018; UN-Habitat, 2016; UNDP, 2016; United Nations General Assembly, 2015; WHO, 1997). Urbanisation and population growth have led to the prediction that 75% of the world's population will live in cities by 2050 (UN-Habitat, 2016). Metropolitan areas play a crucial role in sustainable and equitable development, as the concentrated population creates challenging living conditions (da Cruz et al., 2020; UN-Habitat, 2016). Population growth will increase demand for activities and amenities, and raise house prices. The city centre is usually the most desirable area; it has better access to public transport and a walkable-friendly design, reducing the need for individual motorised travel. However, high property prices reduce diversity, as only a small proportion of the population can afford to live there (Padeiro et al., 2019). This can lead to a situation where the most deprived individuals are pushed into the least-accessible areas with poor facilities. These people have fewer mobility options, higher transportation costs and commuting time, and may even be excluded from certain activities (Currie and Delbosc, 2010; Delbosc and Currie, 2011a).

In this context, several studies have explored the relationship between walkability and socio-economic status, with contradictory results (King and Clarke, 2015; Su et al., 2019; Thornton et al., 2016). Most studies of the relationship between a walkable environment and socio-economic status have examined the North American and Australian contexts, where the spatial distribution of socio-economical groups is more marked (Cowie et al., 2016; King and Clarke, 2015; Thornton et al., 2016). Only a few studies have been carried out in the European context (Gullón et al., 2017). Moreover, there is a lack of research in the context of European metropolitan areas using spatial autocorrelation. Most studies use simple regression models and do not consider the

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spatial proximity of areas (Cowie et al., 2016; Gullón et al., 2017).

In Europe, the population distribution has been shaped by different patterns (Munoz, 2003), with different consequences. More specifically, in Portugal, it is known that in the Lisbon Metropolitan Area (LMA) different socio-economic groups are found in environments with different levels of accessibility (Garcia et al., 2018; Santana et al., 2007). However, little is known about the distribution of walkability.

Therefore, in this paper we evaluate the relationship between the socio-economic status of the population and walkability in the LMA. Given the diversity of land use, we limit our focus to the urban zone, and exclude all natural and rural areas.

2. Background

The United Nations New Urban Agenda defines 17 Sustainable Development Goals that are intended to promote healthy living and wellbeing by creating inclusive, safe, resilient and sustainable cities (UN-Habitat, 2016). The promotion of walkable environments is seen as crucial for sustainable development, and is used as a strategy in planning policies such as new urbanism and smart growth development to create and requalify urban areas (Bereitschaft, 2017; Higgs et al., 2019). Walkability is normally evaluated with multidimensional indexes. The most-used measure was developed by Frank et al. (2006). It is composed of residential density, intersection density, retail floor area ratio and land use mix. These factors are clearly related to the three built environment Ds that influence travel: density, design and diversity (Cervero and Kockelman, 1997), or the five Ds: the original three Ds, plus destination accessibility and distance to transit (Ewing and Cervero, 2010), which some authors see as a function of the original three Ds (Vale and Pereira, 2016a). While an overall index makes it easy to quantify and compare the walkability of a given area, an aggregate value is less useful for stakeholders and practitioners, as it may conceal which dimension is most important.

An environment that supports the use of active and public transport modes can reduce socio-spatial inequities (Badland et al., 2014; Giles-Corti et al., 2016). Furthermore, one that promotes affordable modes such as walking and cycling can benefit health, traffic management, air quality and the economy (Giles-Corti et al., 2016). The literature shows that living in unwalkable environments has negative consequences for health and safety, and increases the risk of obesity for the disadvantaged population that lives in these settings (Santana et al., 2009). Moreover, the benefits of active travel are especially important for disadvantaged and vulnerable populations, as they find it more difficult to access other, more expensive, means of transportation (Adkins et al., 2017). Accessibility is another important aspect of sustainable development, as it defines several aspects of daily life, with impacts on wellbeing (Delbosc and Currie, 2011a), and has been found to be closely related to inequity in many cities, including Lisbon (Garcia et al., 2018; Page et al., 2018). In fact, the mobility pattern that results from a lack of accessibility can, in itself, be a good indication of socio-economic status.

In the LMA, previous studies have found that the most-excluded individuals make fewer non-essential trips. This is a result of the high level of car dependency, as many opportunities are only accessible by this mode (Pritchard et al., 2014). On the one hand, the high level of car dependency reflects the lack of integration of land use and the transport system; on the other hand, it also reflects the socio-economic characteristics of the population (Adkins et al., 2017; Ewing and Cervero, 2010). In general terms, groups with higher socio-economic status can afford to live in places with better residential accessibility, and use more expensive modes of transportation, namely the car.

However, there appears to be no relationship between residential accessibility and social group or income. While Koschinsky and Talen (2015) reveal that many suburban areas are associated with the combination of higher-income individuals and poorer walkability, urban areas with lower-income populations in historical zones frequently have better accessibility.

Urban green areas are another very important aspect, as they contribute to better living conditions and a healthier environment (Picavet et al., 2016; Ward Thompson et al., 2016). They have also been found to improve social interaction and integration (Picavet et al., 2016; Ward Thompson et al., 2016), improve mental health and reduce stress levels, and reduce health inequities (Krekel et al., 2016; Ward Thompson et al., 2016). Their importance is reflected in the fact that the equitable distribution of green areas is defined by law in several countries. Nevertheless, in reality, best-practice is not always achievable (Sarkar et al., 2015), and many neighbourhoods lack green space. Recent studies in several European countries highlight inequal access to green areas, especially for deprived populations and disadvantaged parts of cities (Goldenberg et al., 2018; Iraegui et al., 2020; Wüstemann et al., 2017).

A sustainable environment should include an accessible transportation system that enables individuals to reach important destinations by various modes. These modes incur costs with different effects on different socio-economic groups (Delbosc and Currie, 2011b; Vale, 2020). In particular, the inequal distribution of walkable environments can increase transportation costs for the most-deprived population. Thus, over the past decade, transport planners have paid greater attention to issues of access equity, taking into account the needs of different socio-economic groups (Adkins et al., 2017; Bereitschaft, 2017; Carleton and Porter, 2018; Delbosc and Currie, 2011b).

While private and motorised modes increase accessibility and improve individual mobility, they are less-available to poorer and more disadvantaged groups. The lack of transport options can not only be the result of social exclusion, but also reinforce it. A poor public transport network has a greater impact on disadvantaged sections of the population as it prevents individuals from reaching workplaces and education, participating in social and community activities, and makes accessing healthcare facilities difficult (Delbosc and Currie, 2011a). These problems can be partly reduced by a walkable environment, as the aim is to reduce the distance that has to be travelled to reach important activities. However, although it can improve the health of populations and increase equity (Santana et al., 2009) it also increases property prices (Carmona et al., 2018; Mulley and Tsai, 2013). In turn, higher property values tend to attract wealthier residents and exclude poorer groups (Büttner et al., 2018), which suggest that walkability might be associated with high-income neighbourhoods. In most European cities, tourism pressure has also increased housing prices, reducing the availability of affordable housing in more accessible central areas (Biagi et al., 2015; Santos, 2019), which also offer better walkability. By (unintentionally) increasing house prices, walkability might reduce the ability of individuals from poorer socio-economic groups to live in certain neighbourhoods (Bereitschaft, 2019; Diao and Ferreira, 2010; Kim, 2020).

These considerations highlight the impact that the built environment can have on the spatial distribution of the population. In theory, the most walkable places are most valuable, and only affordable for high-income socio-economic groups (Gullón et al., 2017). In practice, the distribution of the population differs from city to city, and a particular area might be the historical home of a particular socio-economic group (Gullón et al., 2017). Moreover, the spatial distribution of the most walkable places is not equal across countries and cities, and is not always representative of the socio-economic status of the local population.

The above observations highlight that the built environment plays an important role in social equity. It is therefore no surprise that it is a central principle in the Sustainable Development Goals, which seek to ensure minimum social, economic and environmental conditions for all individuals or groups. A lack of walkability, in particular, can result in higher car use, which increases noise, air pollution and accidents (Beder, 2000). In general, equity is important because disadvantaged groups tend to suffer the burden of environmental problems more than others (Adkins et al., 2017) due to a lack of residential options. Beder (2000) points out that disadvantaged people cannot afford to live in a walkable, accessible built environment, while identifying and quantifying the

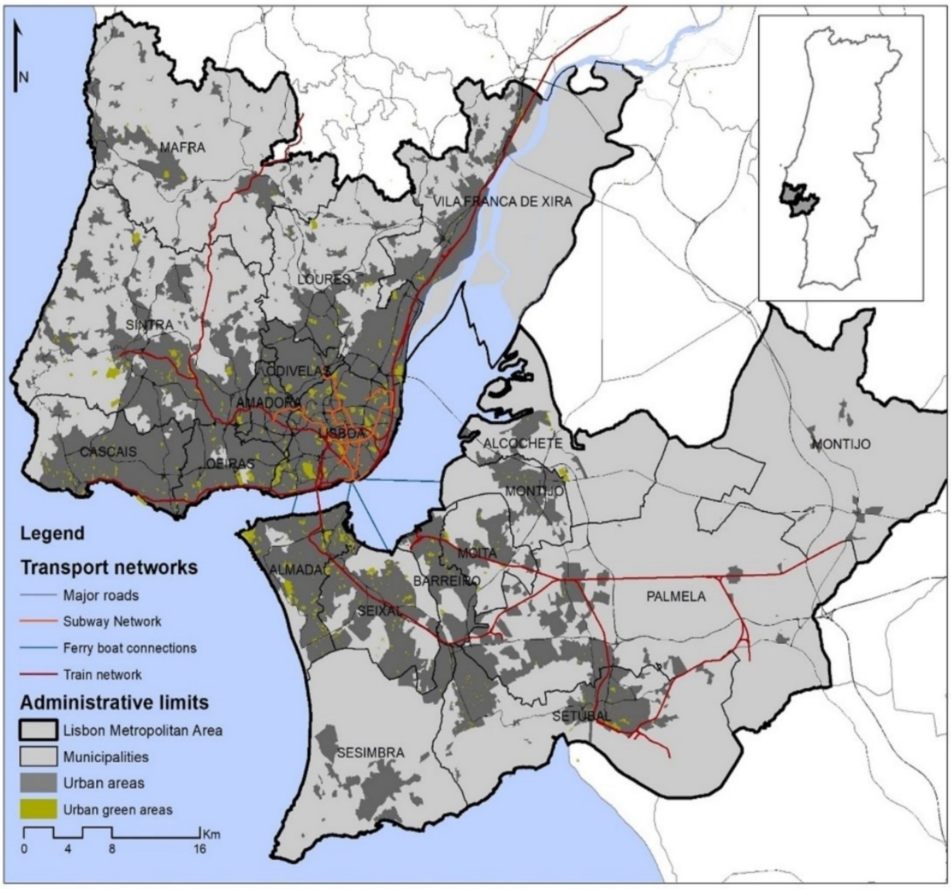

Fig. 1. The Lisbon Metropolitan Area (based on the Urban Atlas, OpenStreetMap and INE data).

relationship between walkability and socio-economic status can help to develop interventions that reduce mobility disparities (Adkins et al., 2017). This is particularly important in the LMA, which has a high level of car dependence and a lack of public transport, resulting in high accessibility disparities (Santana et al., 2009; Santos, 2017).

3. Methodology

3.1. Study area

The LMA is an administrative division that is composed of 18 municipalities and 211 civil parishes (34,937 census blocks). It represents 3.3% of the total area of Portugal, with approximately three million inhabitants (25% of the Portuguese population). In economic terms, it contributes to over 36% of the national GDP. It is composed of high-density central neighbourhoods along with a diversity of both low- and high-density suburbs. Residential land use predominates in most suburbs, and public transport supply is poor (Santana et al., 2009; Santos, 2017).

In the LMA, high-density areas are found alongside low-density zones and the urban space can be defined using the National Institute for Statistics' (INE) classification of census blocks. At least one of the following conditions must be met: 1) the zone is classified as an urban area in the official master plan (Plano Director Municipal); 2) it is part of a census tract with a population density above 500 inhabitants per square kilometre; or 3) it is a place with more than 5000 inhabitants (INE, 2014a). All census blocks with fewer than two buildings, dwellings, families, or residents are excluded (INE, 2014b). We adopted this methodology, and indicators were calculated for census blocks classified as urban space (INE, 2014a). We designate this as the Urban Lisbon Metropolitan Area (ULMA) (see Fig. 1). This area has 2,672,067 inhabitants, representing 95% of the LMA population.

3.2. Data and methods

Our analysis of the relationship between walkability and socio-economic status was broken down into several steps. First, the socio-economic index and walkability indicators were calculated and mapped. Then, their spatial randomness was evaluated using GeoDa v.1.14[1] software. Maps were created based on 999 permutations, and the p-value was set at 0.05. To evaluate the combined randomness of measures, global and local bivariate spatial autocorrelations were run between the socio-economic index and walkability indicators. Finally, the Gini coefficient was calculated to evaluate inequity between walkability indicators, namely access to green areas and public transport, and diversity (number of activities).

3.2.1. Socio-economic status

Our socio-economic status (SES) index draws upon earlier studies of

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[1] Available to download for free at https://spatial.uchicago.edu/software.

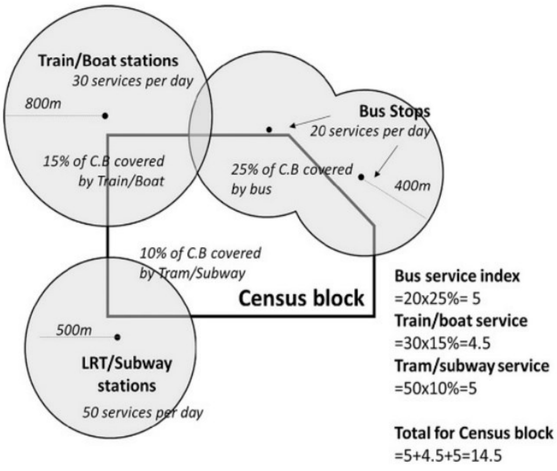

Fig. 2. Public transport index. Adapted from Delbosc and Currie (2011c).

the LMA and other Mediterranean contexts (Gullón et al., 2017; INE, 2014b; Ribeiro et al., 2017). As income data are not available at the census block level in Portugal, we used property value as a proxy. Data were scraped from a real estate website (www.imovirtual.com) and took the form of geographical coordinates of residential property that was for sale in November 2018 (a total of 18,866 datapoints were obtained). They therefore reflect the spot market (asking price), which has been shown to be more accurate than the transacted market value (Boeing et al., 2020). As shared accommodation has increased property values in some neighbourhoods of Lisbon (Carvalho et al., 2019), rental properties were excluded. In order to make comparisons, the price per square metre (€/m^2) was calculated in all cases. These points were used to interpolate a surface in ArcGIS 10.6, following the empirical Bayesian kriging method, to predict a final property value for each census block, calculated as the value of the centroid.

The final SES index combined three data sources: first, the INE's socio-economic description of the Porto and Lisbon metropolitan areas; second, the Portuguese version of the European Deprivation Index (Ribeiro et al., 2017); and third, property values (as described above). The latter indicator was included following Gullón et al. (2017) who show that, for Madrid, property value is an individual socio-economic descriptor. The overall index therefore took into account education, housing conditions, occupation and property value. It was calculated by principal component analysis, and a full description of the method can be found in Appendix 3.

3.2.2. Walkability measures

Walkability was calculated for each census block, taking into account a 500 m buffer to control for the modifiable area unit problem (Openshaw, 1983). It was measured as six dimensions: *i)* density; *ii)* diversity; *iii)* design (the three Ds of the built environment); together with *iv)* slope; *v)* public transport accessibility; and *vi)* the extent of green areas. *Density* was measured as dwelling density. *Diversity* was measured as the number of different activities, based on points of interest, classified into six types: retail; entertainment; civic and institutional; food-related; office; and recreation. The resulting indicator therefore ranged from 0 to 6. *Design* was measured as the density of road intersections (nodes) with four or more links. *Slope* was measured as the percentage of the census block buffer area with a slope below 8%. This value conditions walking as, under Portuguese law, it is the reference value for accessible design.

Public transport accessibility was evaluated following Currie and Delbosc (2010) and Delbosc and Currie (2011c) methodology, adapted to Lisbon (see below). Public transport provision was calculated as an index that considered the level of service within walking distance of each census block. Modes included bus, train, tram, and ferryboat services, and was calculated as follows:

1. A General Transit Feed Specification (GTFS) dataset of bus and tram stops, and train and ferry stations was obtained. This indicated the location of each stop/ station for all rail, bus, tram and ferry routes for all LMA operators;
2. Using the *BetterBusBuffers* ArcGIS tool, service frequency was calculated as total arrivals per day for each stop/ station;
3. A walk buffer was calculated for each stop/ station. We apply the two most common thresholds given in the literature: 400 m and 800 m, representing a 5 and 10 min walk (Vale and Pereira, 2016b). In the case of subway stations and tram stations/ stops, we selected our criteria based on an earlier study of residents' willingness to walk to reach public transport (Vale et al., 2018), therefore we assumed the following thresholds:
   a. Train stations: 800 m;
   b. Subway stations and Light Rail Transit (LRT) stops: 500 m;
   c. Ferryboat stations: 800 m;
   d. Bus stops and trams: 400 m;
4. Where two buffers on the same route in the same direction overlapped, they were merged to avoid counting the service twice.

The final public transport accessibility index was calculated for each census block following the formula given below (see also Fig. 2):

$$PT_{index,CB} = \sum_{n} \left(\frac{Area_{Bn}}{Area_{CB}} * PT \right)$$

where PT_{index} is the public transport provision index for the census block, CB is the census block in question, n is the number of walk buffers to stops/ stations in each CB, B_n is the buffer n for each stop/ station in each CB, $Area_{CB}$ is the spatial area of the CB, and PT is the service level (number of bus/ tram/ train/ ferry arrivals per day).

Green areas were identified following the method given in Kabisch and Haase (2014). Specifically, the Urban Atlas was used to identify land types classified as "green urban areas". Given the limitations of remote sensing data, this information was complemented with the green areas identified in OpenStreetMap, considering the classes described in Appendix 1. Two green area indicators were created: *i)* the percentage of green area in the census block buffer; and *ii)* the total green area (hectares) in the same buffer. These indicators highlighted both the availability and proximity of green areas, taking into account the 500 m buffer in census block boundaries.

Table 1 shows descriptive statistics for all indicators and indexes.

3.2.3. Spatial autocorrelation

Moran (1948) was used to evaluate the spatial randomness of the SES index and walkability indicators. We also calculated a local indicator of spatial association (LISA) for the considered urban areas, in order to map clusters of socio-economic groups and walkability across the ULMA. Matrix weights, based on a Euclidian distance of 1.5 km from each census block centroid were used as this distance is frequently referred to in the literature as the perception of the individual neighbourhood (Brownson et al., 2009; Forsyth et al., 2008; Forsyth et al., 2007). The initial autocorrelations were extended by a bivariate spatial correlation to describe the degree to which the value for a given variable at a specific location was correlated with its neighbours for a different variable (Anselin and Rey, 2014). In this paper, we evaluate a matrix made up of the SES index and the six walkability indicators.

3.2.4. The Gini coefficient and the Lorenz curve

The Lorenz curve (Lorenz, 1905) and the corresponding Gini index (Gini, 1912) are frequently used to measure inequity in economics, as well as a variety of other fields, including transportation and

Table 1
Descriptive statistics for calculated indicators.

Dimension	Indicator	Descripton	Source	spatial unit	Descriptive statistics ($N = 25{,}885$) Min	Max	Mean	Std. Dev
Socio-economic status indicators	SES_index	SES Index	authors		−3.80	4.35	0.00	1.00
Census block characteristics				Census blocks				
	Area	Census block area (ha)	INE 2011		0.03	370.00	9.38	7.25
	Perimeter	Census block perimeter (meters)			71.83	10,838.80	454.64	529.35
Built environment measures	**Density**							
	Dwellings	Residential density (ha)	INE 2011		0.11	651.93	31.18	37.29
	Diversity			500 m buffer of census block				
	POIs	Number of activities (Retail, Entertainment, Civic and institutional, Food-related, Office, Recreation)	HERE WeGo		0.00	920.00	35.98	76.84
	Variety	Variety of activities (0–6)	HERE WeGo		0.00	6.00	3.10	1.65
	Design							
	Connectivity	Density of nodes with four or more links (ha)	HERE WeGo		0.00	1.94	0.21	0.19
	Green Area							
	Per_Green_Area	Percentage of area occupied by urban green areas	Urban Atlas 2016 and Openstreetmap		0.00	46.15	3.85	5.61
	Tot_Green_Area	Total of green area (ha)			0.00	117.86	4.15	6.32
	Slope							
	Slope_8Perc	Percentage of area with a slope <8%	Digital Terrain Model (30 m resolution)		10.56	100.00	87.85	14.19
	Accessibility							
	Acc_TPTrips	Proportion of public transport daily trips for 400 m, 500 m and 800 m public transport buffers	city's open data portal[1]	Public transport buffers	0.00	4549.43	255.24	492.34

INE 2011: Instituto Nacional de Estatística, population census 2011.
1) http://lisboaaberta.cm/lisboa.pt/index.php/pt.

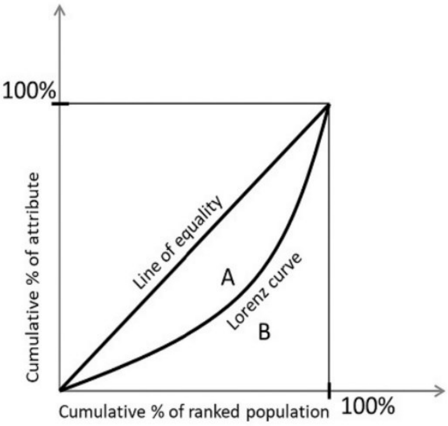

Fig. 3. Hypothetical depiction of the Lorenz curve for attribute Y. The Gini index is calculated as the ratio between the areas A/(A + B).

accessibility analysis (Carleton and Porter, 2018; Lucas et al., 2018). The Lorenz curve is a graphical representation, across a population, of a cumulative variable and it can be used to evaluate any designated measure against a total considered population. The Gini index is the proportion of the area between the line of equality and the Lorenz curve (see Fig. 3), and ranges from 0 to 1. A value of 0 indicates complete equality, while a value of 1 indicates complete inequity (Ben-Elia and Benenson, 2019). We calculated the Lorenz curve and the Gini coefficient using the REAT software package[2] for R to evaluate three walkability variables: the public transport accessibility index, the number of activities, and the total green area (ha).

4. Results

4.1. Socio-economic status

The SES index map (Fig. 4) reveals that SES is highest in the city centre and areas on the north bank of the Tagus river. Here, property values, and the proportion of the population with a university degree are highest (maps of all indicators are shown in Appendix 2). SES is lowest in clusters that ring Lisbon's northern and southern suburbs. Other areas are located near Sintra (to the west) and the rail network linked to the Azambuja train station (to the north). No clear pattern could be identified for places located further from the city centre.

4.2. Walkability indicators

Fig. 5 depicts several built environment dimensions. The analysis of the three main walkability measures (*density*, *diversity* and *design*) revealed two main findings. On the one hand, values are highest for the Lisbon municipality, together with a few areas surrounding the train network on the north bank of the river and ferryboat stations. This result highlights a transit-oriented pattern. Public transport accessibility is better in these areas, but not as high as in the city centre, mainly due to the subway network. On the other hand, values outside these areas are low for all three dimensions, pointing to car dependency.

Results for the percentage of green areas followed a similar pattern, showing that provision is not equally distributed. Overall, however, they are more frequent in the municipality of Lisbon and less present in the suburbs. This result is partly a consequence of our decision to only consider formal green areas, and exclude forest and other types of non-urban land use. As expected, the analysis of slope highlighted the plains on the south bank of the river, the hilliness of the city centre, and other high points in the suburbs.

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[2] Available at https://cran.r-project.org/web/packages/REAT/index.html

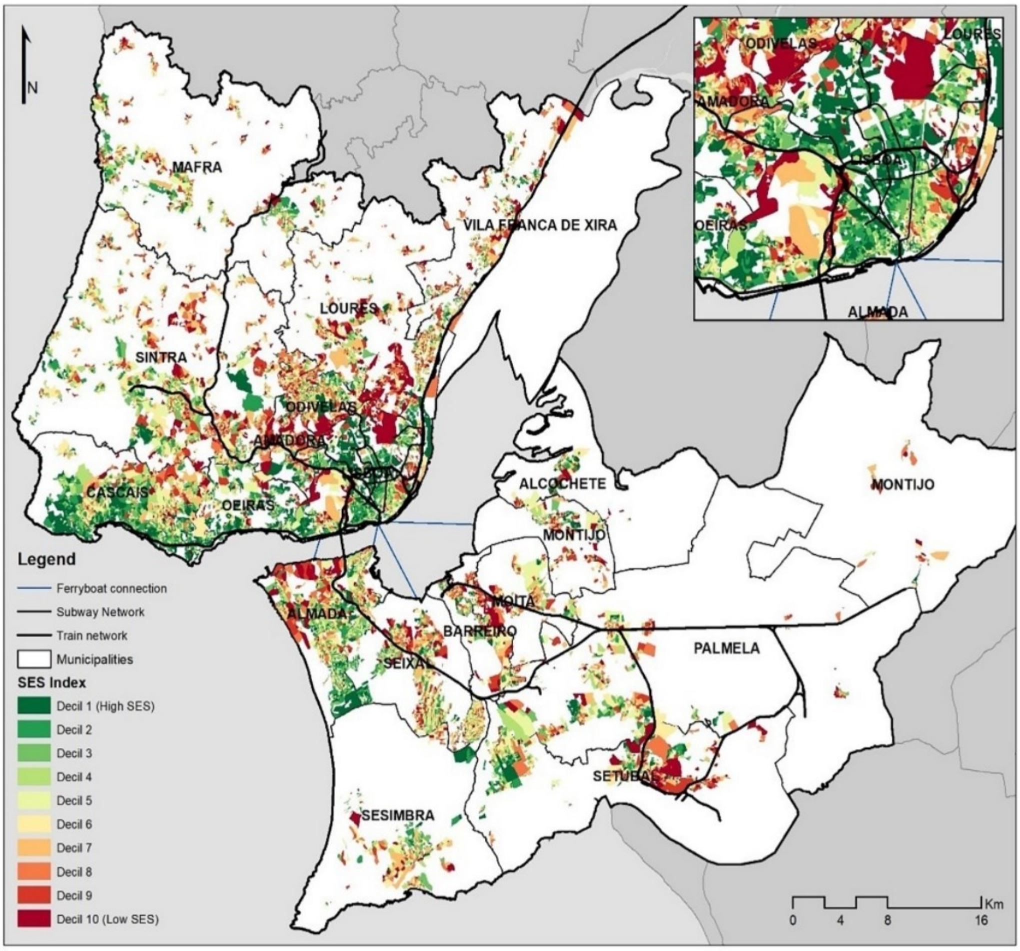

Fig. 4. Distribution of the socio-economic status index in the ULMA.

4.3. Local and global spatial autocorrelation

The SES index map (Fig. 6) reveals clusters of low-low LISA groups in Lisbon city centre and on the north bank of the Tagus river, indicating populations with higher SES. It also shows high-high clusters (populations with low SES) on the south bank of the river and in a zone that is further from the city centre. Global Moran's I indicator confirms the spatial autocorrelation of SES index, but with a small value ($I = 0.257$, pseudo p-value $=0.001$). In fact, the observed clusters are closely related to the occupation and housing conditions of the population (LISA maps and Moran's I are shown in Appendix 4).

Global spatial autocorrelations for the six walkability measures (Fig. 7) confirm that all are spatially autocorrelated, yet have significantly higher values than SES indicators. The lowest value corresponds to *green areas* ($I = 0.384$, pseudo p-value $= 0.001$), followed by *density* ($I = 0.426$, pseudo p-value $= 0.001$), and the highest corresponds to *public transport accessibility* ($I = 0.769$, pseudo p-value $= 0.001$). Values are similar for *design* and *diversity*, reflecting a higher level of clustering.

The *density* LISA map highlights a high-high group that lives close to the rail network, suggesting that this could be a useful way to promote transit-oriented development. However, it also illustrates the low overall density of the ULMA, as most of the area consists of low-low clusters. The *diversity* map highlights that diversity is highest in the city centre and the area surrounding the Sintra railway line (to the west). The same is true for the northern bank of the Tagus river (following the Cascais railway line). The further from the city centre, the lower the number of activities. The *design* LISA map confirms the low density of the ULMA: higher network connectivity is found in the city centre and areas closer to train stations. Historical zones have the highest connection density, while census blocks further away from the urban centre are less dense and have poorer road network connectivity.

The *green area* LISA map confirms the previous assumption in the green area map, reinforcing that Lisbon municipality is best-served in terms of urban green areas. While other areas are covered by forest, they have none of the facilities that are important in urban areas. The topography (*slope*) LISA map shows the location of a few plateaus and the lowlands bordering the Tagus river. Finally, the *public transport accessibility* map illustrates a clear difference between the city centre and the rest of the ULMA (Moran's I is highest).

4.4. Bivariate spatial autocorrelation

Fig. 8 illustrates the bivariate spatial autocorrelation LISA maps for the SES index and walkability indicators. The Global Moran's I indicator confirms the spatial autocorrelation for all walkability indicators, although most of the Global Moran's I values are small. The highest correlation is in *public transport accessibility* ($I = -0.166$, pseudo p-value $= 0.001$). Locally, the map reveals a cluster of high public transport

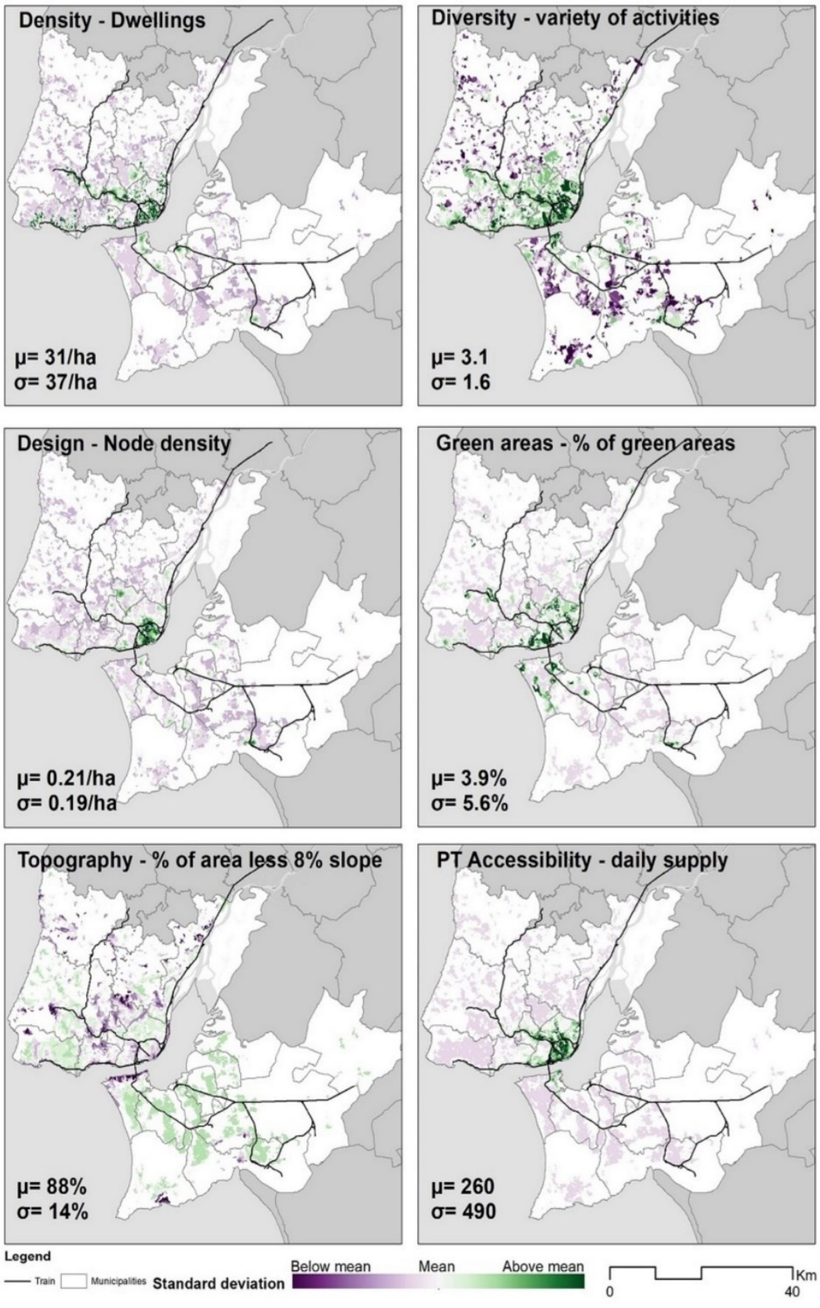

Fig. 5. Built environment distribution maps (μ = mean; σ = standard deviation).

supply and a group with low SES around Sintra's railway line (to the West of Lisbon). Slope has the lowest value ($I = -0.044$, pseudo p-value = 0.001). Overall, locally, these LISA maps indicate the random distribution of high and low correlations without a clear pattern.

Fig. 9 illustrates the Lorenz curve and the Gini coefficient (G) for activities (variety), public transport accessibility, and green areas (hectares). The inequity indicator is highest for *public transport accessibility* (G = 0.7268), where almost 80% of the population only has access to 20% of total public transport supply. The second highest inequity indicator is *green areas* (G = 0.6655). In this case, almost 80% of the population only has access to 40% of urban green areas. Finally, inequity is lowest for the *number of activities*: G = 0.6361, which is similar to the value for green areas.

5. Discussion

The SES index and walkability indicators have very distinctive patterns. Overall, Global Moran's I is small ($I = 0.257$ pseudo p-value =0.001), indicating that SES is spatial autocorrelated but with very low values. Nevertheless, a local-level evaluation, LISA reveals low SES

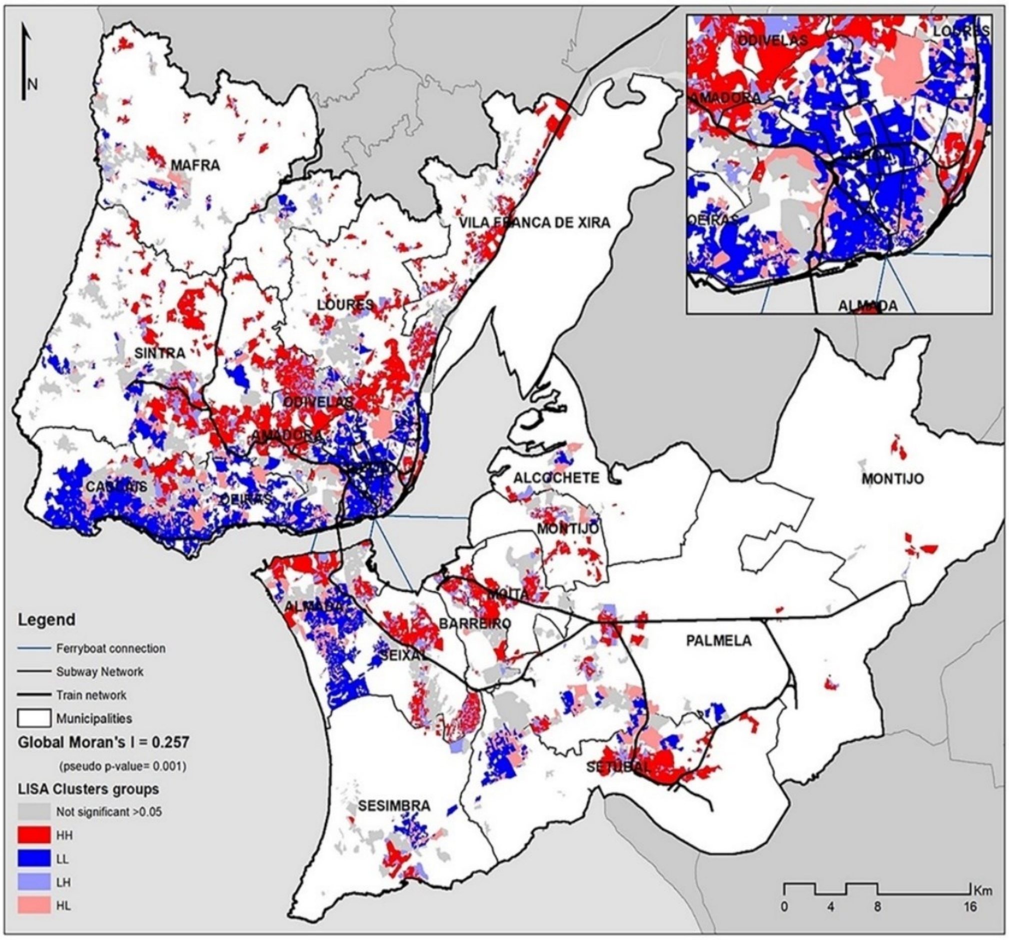

Fig. 6. Global Moran's I statistic and LISA map of the SES index.

clusters in a ring made up of the northern suburbs. SES is highest in the city centre, and areas on the northern bank of the Tagus river. These results confirm the clusters found by the INE (INE, 2014b). They are also similar to findings from other European cities, where development has resulted in different populations being located in different parts of the city, and are unlike patterns found in the United States where SES segmentation is normally clearer.

Turning to walkability, there is clear evidence of spatial clustering. This is confirmed by the global Moran statistic, which ranges from $I = 0.384$, pseudo p-value $=0.001$ (green areas), to $I = 0.769$, pseudo p-value $=0.001$ (public transport accessibility). Maps of walkability indicators and LISA maps clearly distinguish between peripheral ULMA areas and the city centre. This result is consistent with findings from other studies in different contexts (Mayne et al., 2013) and reveals clear differences in the development and current occupancy of the ULMA (Santos, 2017). There is a high degree of inequity, with an impact on mobility patterns, especially commuting time. Commuting time is an important element in the INE's definition of SES, and the municipality of Lisbon has lower commuting times than the rest of the ULMA (INE, 2014b). Walkability is better in dense highly-urbanized areas served by major transportation infrastructures, and in clusters found in previous studies (INE, 2014b; Santos, 2017).

Our results point to global spatial association between the SES index and walkability indicators, yet with low Global Moran's I values. Moreover, our bivariate LISA maps reveal clusters with low SES and high values for walkability indicators, such as density and public transport accessibility. This pattern complement previous findings from Pereira and colleagues (Pereira et al., 2021), which evaluate the correlation between SES and walkability conditions for four groups of census tracks, considering 15 minutes distance from the city centre. The authors did not find an association between SES and walkability indicators based on a Person correlation. However, the closest census track from the city centre has the highest correlation between SES index and the different walkability indicators considered. The closest areas from city centre match our clusters of the LISA maps with high SES groups and high values for walkability indicators on the Lisbon city centre, as well as the areas surrounding train stops. In fact, our study confirms the important difference between the city centre and the rest of Lisbon Metropolitan Area, including in this distinction the areas surrounding the train stations in areas further from the city centre. The results justify the importance of using the two levels of spatial autocorrelation. As we can see, Global Moran's I is relatively low for the ULMA and gives the level of dispersion of walkability conditions; however, these results can change if we look to a specific municipality or areas at certain distance to the city centre. On the other hand, LISA maps identify the location of high clustered areas on low and high walkability conditions. With these two metrics it is possible to obtain a global spatial autocorrelation metropolitan indicator and the identification of local clustered areas of

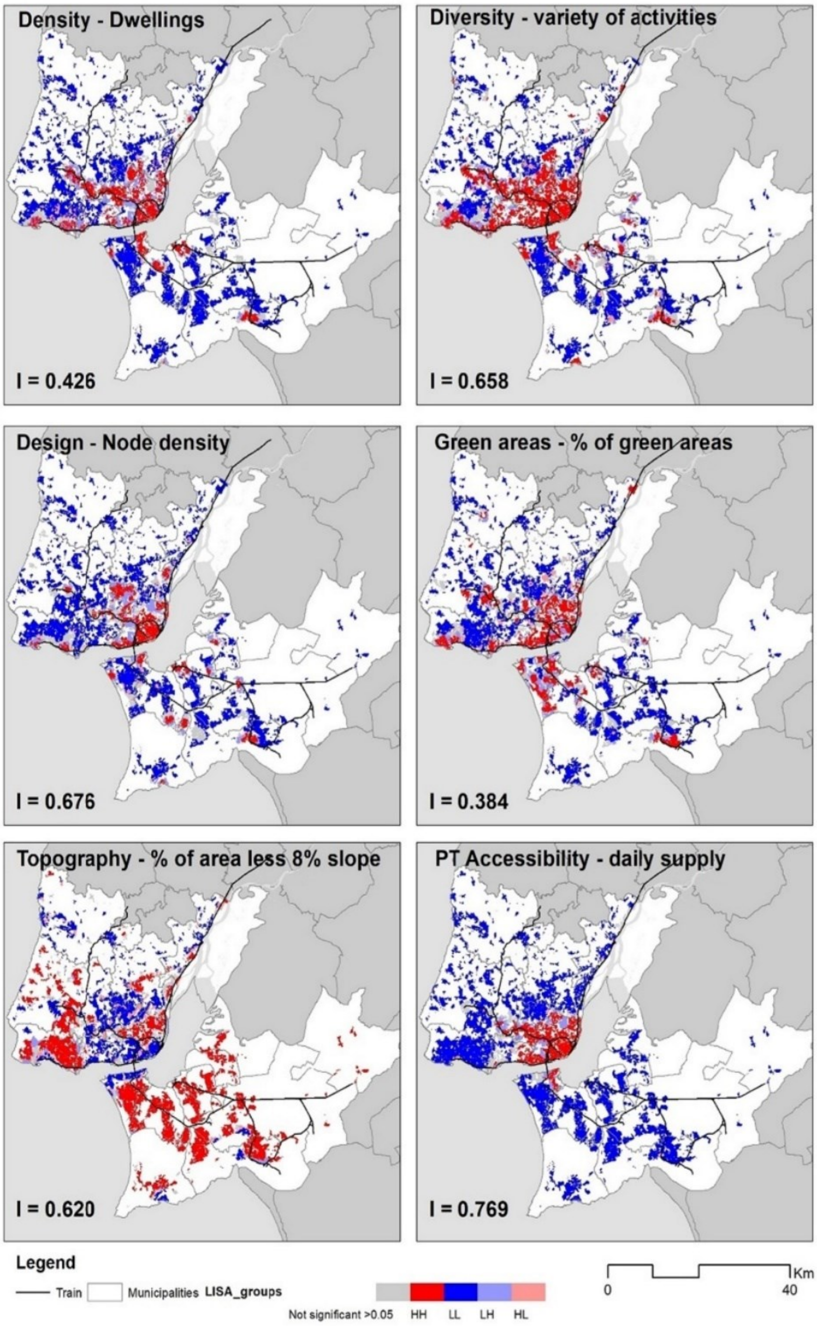

Fig. 7. Global Moran's I statistics and LISA maps of walkability indicators.

walkability conditions.

To the best of our knowledge, the present study is one of the few studies mapping walkable conditions and SES at the same time, using spatial correlation to explain the patterns involved (Cowie et al., 2016; Su et al., 2019). Most previous studies have selected neighbours based on walkability or SES conditions for deeper analysis (King and Clarke, 2015; Sallis et al., 2018). The advantage of our approach is that we can evaluate relative SES and walkability conditions at metropolitan level, considering different levels of social deprivation and pedestrian accessibility.

We found an overall low value for spatial correlation between SES and walkability indicators. However, inequity regarding walkability, especially the unequal distribution of public transport supply, could have an impact on SES. Our results show that public transport accessibility is the most unequal indicator (G = 0.7268), confirmed by the LISA map and Moran's I ($I = 0.769$). This highlights the poor coverage of the rail network—for the past 30 years development in the LMA has supported car dependency, which increases inequity between socio-

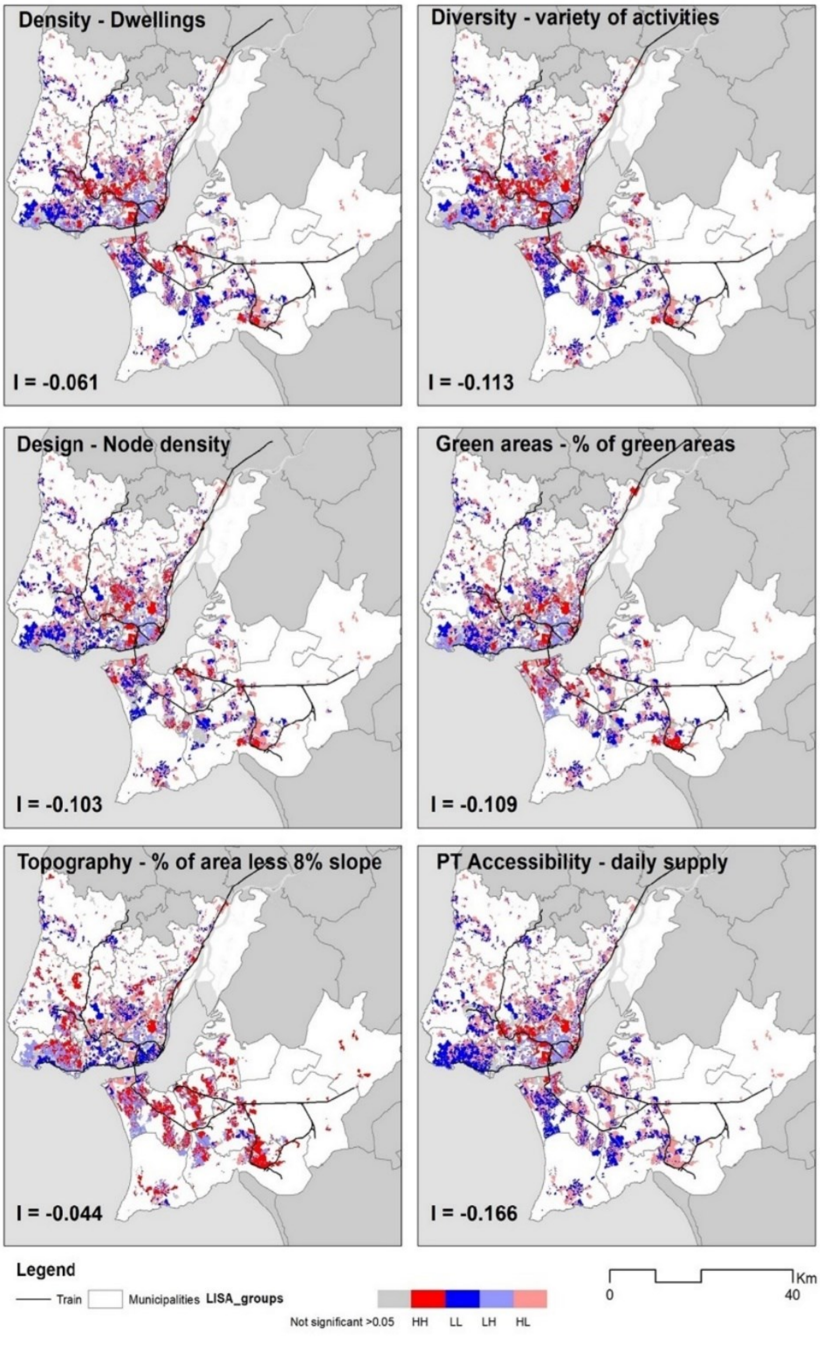

Fig. 8. Bivariate LISA maps for the SES index and walkability indicators.

economic groups (Santos, 2017).

Our results are particularly important when considering previous studies of the LMA, which report that distance to public transport is the factor that distinguishes groups with similar incomes most clearly (Pritchard et al., 2014). Furthermore, the latter authors found no evidence of clustering with respect to socio-economic and accessibility indicators, confirming a lack of population segmentation. Inequity with respect to walkability is alarmingly high in European metropolitan areas, where urbanisation and population growth are pushing deprived groups away from the city centre (Goldenberg et al., 2018; Iraegui et al., 2020). The global character of metropolitan areas results in a competition between business and tourism activities. A more-qualified population and a higher level of tourism has an impact on property values (Carvalho et al., 2019); this, in turn has an impact on the SES distribution, creating inequities (Musterd et al., 2017).

The use of walkability measures to evaluate inequities is consistent with the current literature, especially in a context where transport inequity is thought to increase social segregation and transport poverty

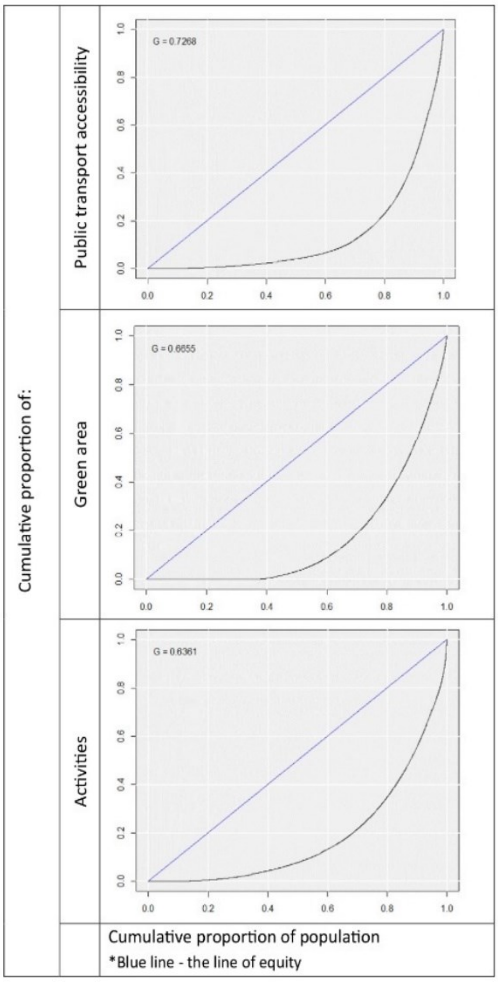

Fig. 9. Lorenz curves and Gini coefficients.

(Burchardt, 2000; Currie and Delbosc, 2010; Delbosc and Currie, 2011c; Lachapelle et al., 2016). In the case of the LMA, this consideration is particularly important, as inequity is greatest with respect to walkability, especially public transport accessibility. This problem increases dependence on individual motorised modes, which are not only harder for the poor to acquire and maintain, but also require middle-class individuals to work more to maintain the accessibility they gain (Vale, 2020). The current inequity in walkability distribution can increase transport poverty as more people rely on their car to travel. This situation is detrimental not only to an individual's economic and physical health, but also society, because of increasing air pollution, noise and spatial segregation (Giles-Corti et al., 2016).

It should be noted that our study has nameworthy limitations. First, the use of the census block as the scale of analysis has several limitations due to different polygons sizes; however, it is the smallest unit of analysis where official data is available to conduct the proposed research. Accordingly, as Table 1 shows, census block sizes vary from 0.03 ha to 370 ha, and this difference leads to a bias with respect to the calculated indicators, especially density indicators. The use of the census block also has limitations regarding the evaluation of walking distances, as the distance aggregated at the census block level is influenced by the dimension and shape of the census block itself. In addition, it has an impact on the catchment area polygon, which can result in an overestimate of the public transport supply. In this paper, we use distances considered as crow flies to ensure comparability with studies that use the same approach (Delbosc and Currie, 2011c). However, we acknowledge that this is an important limitation of our walkability indicators and future work should take advantage of new technologies, and calculate walking distances in the pedestrian network on a more detailed scale, for example, by using a small grid or analyses at building level, instead of indicators aggregated at census block polygons. Additionality, the SES index is an objective measure that was developed from official data collected at census block scale, representing the neighbourhood level. Therefore, it does not reflect individual socio-economic status. Second, our property value indicator does not include social housing, as it is not sold on the open market. Social housing is promoted by the Portuguese government and municipalities, and rents are a function of household income. Third, the data source for population is outdated, but 2021 census data are not yet available. Fourth, OSM data are naturally subject to the limitations of a crowdsourced platform, especially information about the selected green space that indicates if access is public or private. Finally, perceptions of security and safety are other important issues related to walking behaviour. Unfortunately, we were not able to consider them.

Future research should consider travel patterns for different SES groups (Lucas et al., 2018). For example, the distance to pharmacies, hospitals or day care is more important for deprived people, notably elderly or handicapped populations (Currie, 2004; Geurs and Van Wee, 2011; Padeiro, 2017). Moreover, the evaluated walkability conditions are considered in less detail, and are considered at the census block level. Further work could include the equity distribution of the most-detailed walkability conditions such as the presence of trees (Justo

Table 4
PCA quality analysis based on the KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser Meyer Olkin Measure of Sampling Adequacy.		0.712
Bartlett's Test of Sphericity	Approx. Chi-Square	64,279.176
	df	28
	Sig.	0.000

Table 3
Descriptive statistics for SES indicators.

Descriptive statistics	N	Minimum	Maximum	Mean	Std. Deviation
LowEducation	25,885	0.00	100.00	14.4482	8.51924
UniversityDegree	25,885	0.00	100.00	20.3860	18.86183
RentedHouses	25,885	0.00	100.00	23.9660	24.48890
OvercrowdedHouses	25,885	0.00	100.00	11.3737	10.80719
Unemployment	25,885	0.00	100.00	12.9439	10.30134
HighProfessionals	25,885	0.00	67.31	13.8043	10.32634
ManualOccupation	25,885	0.00	100.00	16.8930	11.88131
PropertyValue	25,885	551.50	9166.86	2071.5609	1124.29525
Valid N (listwise)	25,885				

and Silva, 2020), sidewalk width, safety perceptions and other streetscape features (Ewing and Handy, 2009; Zhu and Lee, 2008). Finally, the high proportion of rural areas suggests that methodologies to measure walkability in rural areas within metropolitan areas should be developed, and their role in promoting a more sustainable and equitable city should be explored.

6. Conclusion

The present paper makes an important contribution to our understanding of walkability, and evaluates its distribution as a function of the location of groups with different SES. As far as we know, it is the first to evaluate and map walkability for the entire ULMA. The resulting maps, and global and local spatial autocorrelations give an insight into the socio-economic and walkability situation in the area.

Although we found a bivariate spatial autocorrelation between SES indicators and walkability in the ULMA, the Moran's I value is low. Nevertheless, at local level, our LISA maps identify some hotspots where disadvantaged groups are found. These areas coincide with higher residential density and high public transport accessibility. Inequities are more evident for walkability indicators, where values are highest for public transport accessibility. This finding is significant due to the importance of public transport for sustainable development.

The present paper makes an important contribution to research on equitable and walkable environments in the European context and suggests tools to map and evaluate these environments at metropolitan level. Our results are useful not only for Lisbon, but also other European metropolitan areas. The unequal distribution of walkability, mostly due to a lack of public transport, creates a high level of car dependency in most of the ULMA. Although the lack of coverage affects both low and high SES residents, it has more impact on low-income individuals who are captive users of public transport and cannot afford to travel by car.

Our evaluation of walkability and SES could be used to develop intervention policies that fight social exclusion through the improvement of walkability dimensions. Different walkability indictors are consistent with changes in mobility patterns that affect low and high SES groups differently. In all cases, more sustainable transportation will have a positive effect on all of society.

CRediT authorship contribution statement

Mauro F. Pereira: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing. **David S. Vale:** Conceptualization, Methodology, Writing – review & editing, Resources, Supervision. **Paula Santana:** Writing – review & editing, Supervision.

Declaration of Competing Interest

None

Data availability

Data will be made available on request.

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Appendix 1

Table 1
OpenStreetMap tags (key and value) used to represent urban green areas*.

Key	Value	Description
landuse	allotments	*A piece of land given over to local residents for growing vegetables and flowers.*
landuse	grass	*An area of mown and managed grass.*
landuse	recreation ground	*An open green space for general recreation, which may include pitches, nets and so on, usually municipal but possibly also privately-owned by colleges or companies.*
leisure	garden	*A place where flowers and other plants are grown in a decorative and structured manner or for scientific purposes.*
leisure	park	*A park, usually municipal.*

* Private areas are excluded based on the “private” tag in the description.

Appendix 2

Table 2
Socio-economic indicators making up the SES index.

INE SES typology for Lisbon Metropolitan Area (INE, 2014b)	Portugal deprivation index (Ribeiro et al., 2017)	(Gullón et al., 2017)	Proposed	Code
Average academic qualifications of the resident population (years)	Low education level (≤ 6 years)	Low education defined as % people above 25 years of age with primary studies or below	Low education level (≤ 6 years)	LowEducation
		High education (defined as % people above 25 years of age with university education or above	Population with university degree	UniversityDegree
	Women aged 65 years or more			
Proportion of rented housing (%)	Non-owner		Proportion of rented houses	RentedHouses
				OvercrowdedHouses

(continued on next page)

Table 2 (*continued*)

INE SES typology for Lisbon Metropolitan Area (INE, 2014b)	Portugal deprivation index (Ribeiro et al., 2017)	(Gullón et al., 2017)	Proposed	Code
Proportion of overcrowded housing (%)	Household with <6 rooms		Proportion of private households in conventional dwellings overcrowded (%)	
Proportion of underutilized housing units (%)			*not used*	
	No indoor flushing			
	No bath or shower			
Unemployment rate	Unemployed looking for a job	Unemployment rate	Unemployment rate.	Unemployment
		Part time employment (% workers in part time jobs)	*no data*	
		Temporary employment (% workers in temporary jobs)	*no data*	
	Manual occupation	Manual occupational class (% workers in manual or unqualified jobs)	Manual occupation	ManualOccupation
Proportion of managers, technicians, intellectual and scientific professionals			Proportion of managers, technicians, intellectual and scientific professionals	HighProfessionals
Proportion of population using mainly the car for commuting				
Proportion of population using mainly public transport for commuting				
		Average housing prices (per sq. m)	Average housing prices (per sq. m)	PropertyValue

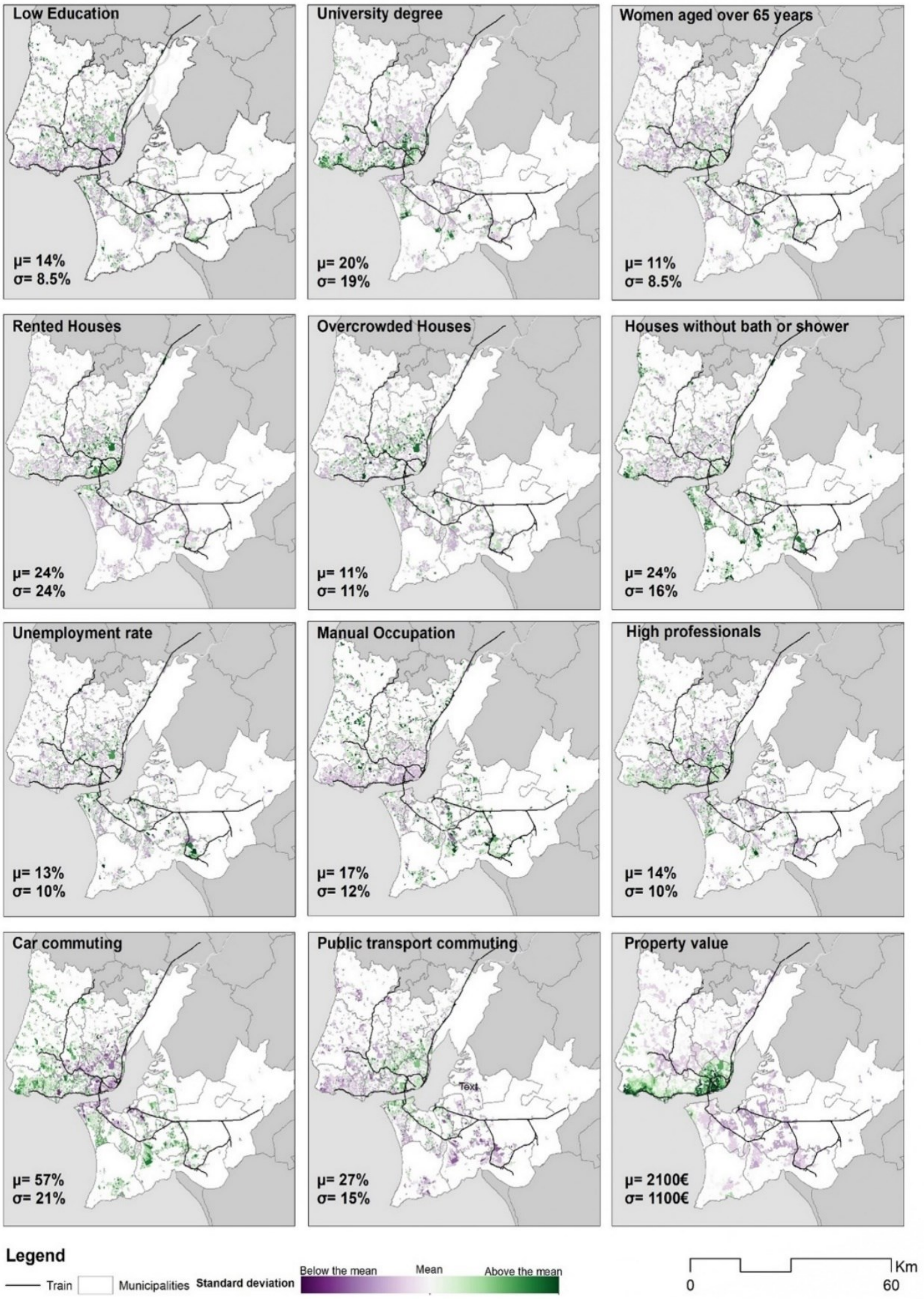

Fig. 10. SES indicators distribution (μ = mean; σ = standard deviation).

Fig. 10 illustrates the distribution of socio-economic indicators across the LMA. No clear pattern is observed in most cases, as higher and lower values are spread across the area. The exception is occupation and housing conditions, where a clear spatial pattern is visible. In the municipality of Lisbon and the waterfront to the west of the city centre (known as the Cascais Line) a higher percentage of the population has a university degree and property values are highest here.

Appendix 3

The PCA analysis was performed considering the indicators given in Appendix 2. Table 3 shows descriptive statistics.

The construction of the SES index follows previous studies that use PCA analysis to describe a population with multilevel socio-economic characteristics (Vyas and Kumaranayake, 2006). The goal is to capture a latent dimension that is described by correlated variables and create a measurement scale for the analysed phenomenon. The most important result is a score that considers the contribution of each variable to the index (Marôco, 2010).

The PCA analysis was performed on a correlation matrix based on the extraction of factors with an eigenvalue higher than 1. KMO = 0.712, (see Table 4) which can be considered acceptable (Marôco, 2010).

The SES index was built using component scores for each census block, implemented in SPSS (v.26). The final index measures deprivation; the lowest or negative values correspond to high SES, and the highest values correspond to the most deprived population (low SES).

	Components		Communalities
	1	2	
LowEducation	**0.559**	−0.168	0.340
UniversityDegree	**−0.873**	0.172	0.792
RentedHouses	**0.469**	**0.664**	0.661
OvercrowdedHouses	**0.619**	0.370	0.519
Unemployment	**0.544**	0.321	0.399
HighProfessionals	**−0.861**	0.048	0.743
ManualOccupation	0.304	**−0.556**	0.401
PropertyValue	−0.361	**0.724**	0.654
Variance Explained	36.702	19.678	

Extraction Method: Principal Component Analysis.
a 2-component extraction.
*Loadings above 0.40 are shown in bold.

Appendix 4

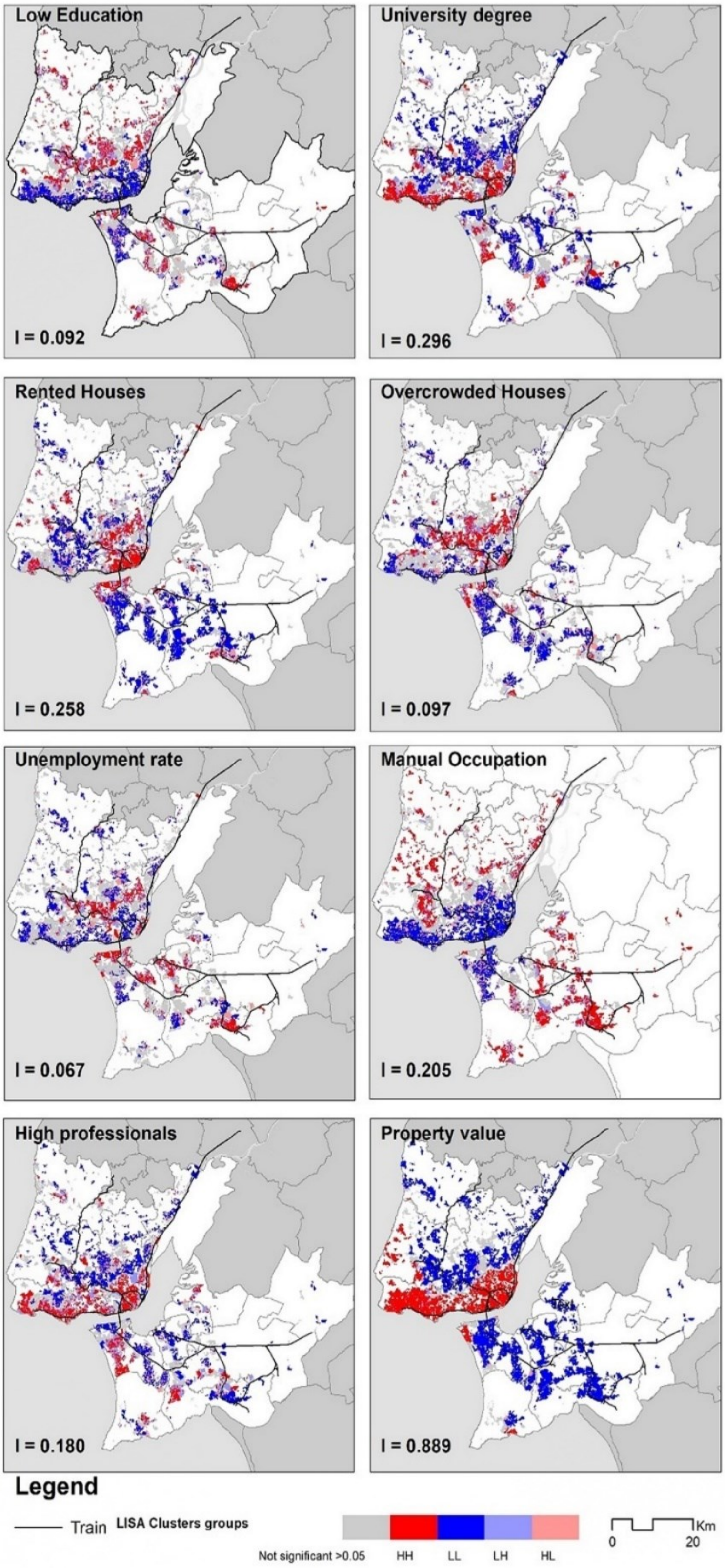
Low Education
I = 0.092
University degree
I = 0.296
Rented Houses
I = 0.258
Overcrowded Houses
I = 0.097
Unemployment rate
I = 0.067
Manual Occupation
I = 0.205
High professionals
I = 0.180
Property value
I = 0.889
Legend
Train
LISA Clusters groups
Not significant >0.05
HH
LL
LH
HL
Km
0
20

Fig. 11. LISA maps for indicators used in the SES index.

Fig. 11 illustrates local indicators of spatial association (LISA) and their respective global autocorrelations. The Global Moran's I values are low in most cases but with a pseudo p-value of 0.001, suggestion a spatial autocorrelation. The exception is occupation and housing conditions, confirmed by the global Moran's I statistic and LISA maps. LISA maps reveal a significant local autocorrelation in specific areas of the LMA. The property value map illustrates clusters, notably a high-value zone in the city centre that extends to the north coast of the Tagus river and a second, low-value zone further from the city centre.

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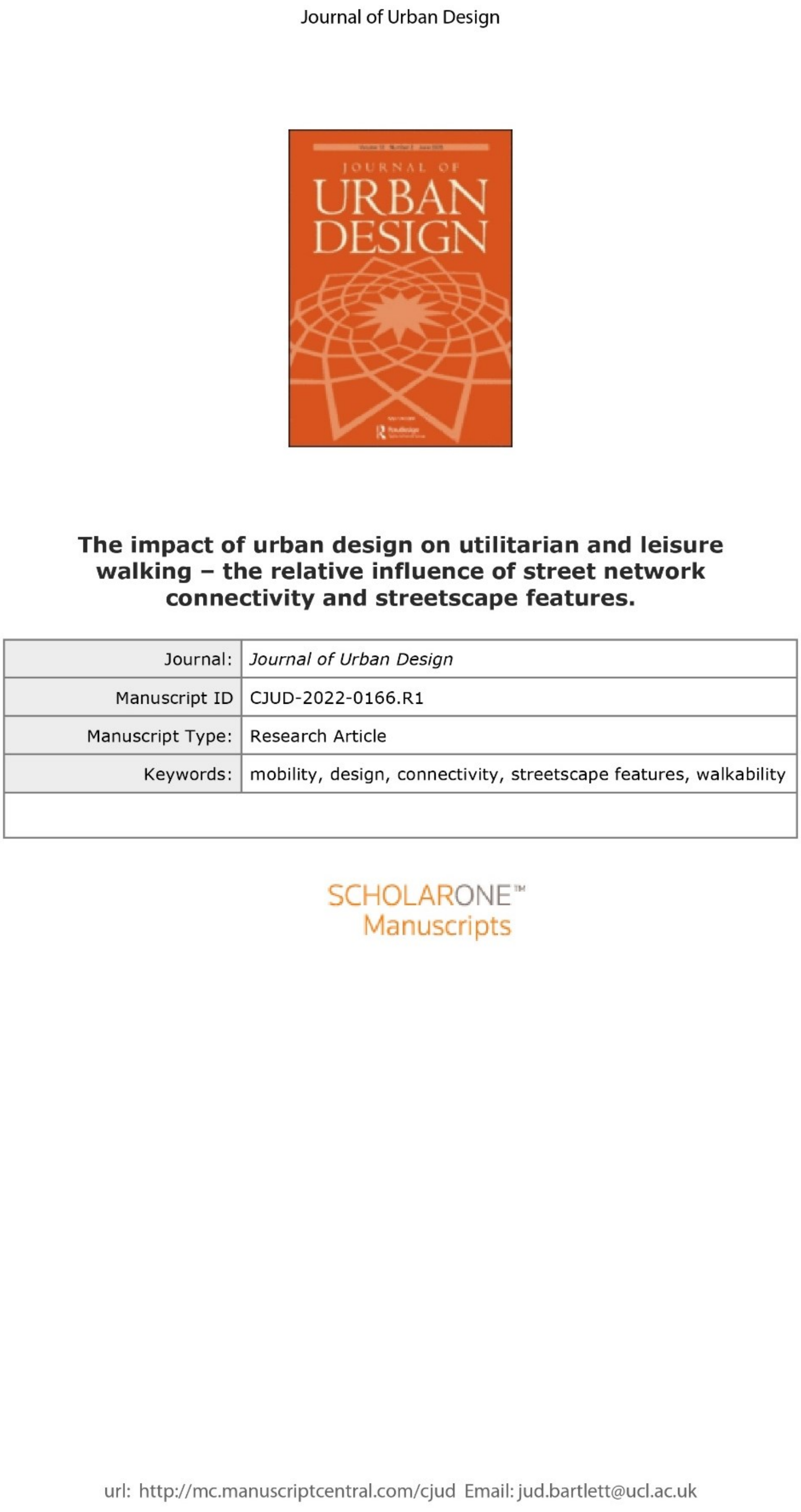
5.5 V. The contribution of design dimension for utilitarian and leisure walking – the relative influence of connectivity measures and streetscape features.



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The impact of urban design on utilitarian and leisure walking – the relative influence of street network connectivity and streetscape features.

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The impact of urban design on utilitarian and leisure walking – the relative influence of street network connectivity and streetscape features

Road network connectivity determines the accessibility of urban activities for pedestrians, while streetscape characteristics have an impact on route attractiveness. Methods used to measure the influence of connectivity and streetscape characteristics on walking behaviour differ substantially, while trip purpose is a key factor. This paper explores the respective contributions of network connectivity and streetscape features to explain walking leisure and utilitarian trips on 740 street segments in Santarém (Portugal). The results show that connectivity measures have greater overall explanatory power. However, the findings highlight the need to consider a variety of design indicators to explain walking behaviour.

Keywords: mobility; design; connectivity; streetscape features; walkability

Introduction

Urban design and urban form of the city shape different aspects of individual routines and behaviour (Blitz and Lanzendorf 2020). Mobility patterns are one of the aspects influenced by urban characteristics (Næss 2012; Ewing and Cervero 2010). Mobility patterns have an impact on aspects like air quality, car accidents, levels of physical activity, and are related with several non-communicable disease (Frumkin, Frank, and Jackson 2004; Barton 2017; Authors, 2020). Assuming the importance of these issues for the sustainability and health of our cities, several international documents suggest the importance of developing and designing cities that support the use of sustainable transportation travel modes (UN - Habitat 2016; Patel et al. 2018). Active travel, that includes walking, cycling, and public transport, is crucial to reduce the negative impacts of mobility patterns in individual health. In this paper we are focused on walking because it is embedded in the different modes of transportation.

The design of urban form and structure of the city, defined at city level, influence walking trips through the dimension of the blocks, the locations of major activities, and the location of mobility infrastructures like public transport (Rynning 2018). Nevertheless, the complexity of walking behaviour is also influenced by the closest context of built environment, and the latter influences individual perceptions of urban qualities (Saelens and Handy 2008; Hillnhütter 2022). The perceptions of urban qualities influence the attractiveness of the street is what mostly impacts the walking trips especially considering different trip motives (Arellana et al. 2019; Kim, Park, and Lee 2014; Steinmetz-Wood, El-Geneidy, and Ross 2020).

The design concept is used to define this urban structure and urban qualities (Ewing and Clemente 2013). The design of the city at metropolitan level is shaped by the road network, which defines public and private space. The design dimension at this level is evaluated by network topological indicators related with the components of this road network. However, at a pedestrian level, this topological aspect is less perceived. At this level, other types of design aspect, which include urban street design or streetscape features, are more important to individual perceptions of public space, and more important to define attractiveness and the consequent choice of walking to this destination (Steinmetz-Wood, El-Geneidy, and Ross 2020). Unfortunately, the evaluation of these streetscapes characteristics is more complex and time consuming.

The qualities of built environment for pedestrian movement have been evaluated by the concept of walkability (Wang and Yang 2019; Frank et al. 2006). Probably, the best-known and commonly-used measure is the walkability index proposed by Frank et al. (2006), which combines three important dimensions: Density, Diversity and Design. *Density* depicts the relationship between residents, buildings or dwellings, and the urban area. Higher density implies that destinations are closer to each other, which makes walking a feasible travel mode. *Diversity* describes the mixture of activity types, land uses, and/or housing types. Generally associated with Density, Diversity is important as it increases the probability that the desired opportunity or destination exists within walking distance. *Design* is more complex to measure and evaluate, as it can represent multiple different phenomena. The density and diversity dimensions have a straightforward approach, but the same is not true for design dimension. The design evaluation by the indicators from the network topological evaluation is the most frequently used. Different connectivity measures were created and evaluated based on the existent road network. However, these indicators miss the details and the aesthetics characteristics that make a street attractive and supportive of the walk movement (Hillnhütter 2022). Nevertheless, these connectivity indicators have been used on several walkability indexes to describe a walkable environment for the design dimension. In literature, these connectivity indicators reveal to be especially relevant to explain walking trips (Saelens, Sallis, and Frank 2003; Frank et al. 2006; Sallis et al. 2016). The importance of connectivity indicators for explaining walking and the time consuming nature of evaluating streetscapes features explains why the design dimension is measured by connectivity indicators in the majority of the literature (Authors 2016).

While the connectivity measures are important for explaining walking trips; the streetscape features have an impact on individuals' perceptions. The authors Ewing and Handy (2009), identify five groups of streetscape characteristics that influence individual perception: imageability, enclosure, human scale, transparency and complexity. The evaluation of these five groups of streetscape features (or urban design qualities, as defined by the author) requires an audit protocol aimed at the collection of characteristics of the street by trained auditors. Technologies like Google Street view or automated image classification reduce time and resource consumption. Nevertheless, the evaluation of streetscape features remains much more complex than evaluate connectivity measures. Other authors have attempted to transform the audit protocol into objective measures, computed through GIS and tridimensional models (Purciel et al. 2009; Yin 2017). However, the relative contribution of connectivity measures and streetscapes qualities to explain walking trips remains unclear. This is particularly important considering the different types of trip motives.

In fact, utilitarian and leisure trips are substantially different and influenced in different ways by the several aspects of the built environment (Kang et al. 2017). Most utilitarian trips are mandatory, in which case the conditions of public space are less important because the trip must be done. On the other hand, leisure trips are more flexible and influenced by the attractive qualities of the street - a more supportive walking street can have a higher number of pedestrians because of these street qualities. The pleasure or satisfaction felt during a trip is crucial for walking and especially for leisure trips (De Vos et al. 2015; Mouratidis, Ettema, and Næss 2019; Kim, Park, and Lee 2014). This difference in walking trip motives reinforces the significance of the relative contribution of the connectivity indicators and streetscape features to explain walking trips for leisure and utilitarian trips. This is especially significant considering the feasibility of changing the urban structure measured by the connectivity indicators or of changing streetscape features (Kim, Park, and Lee 2014; Cambra and Moura 2020).

With the goal of improving active travel, in this case, walking, and considering that the resources are limited, what will be the most effective transformation of the built environment to improve walking? Improving the street network, land use, and mobility systems or improving the streetscape features?

This paper explores the relative contribution of the design, defined by road network and measured by connectivity indicators and streetscape features, to explain walking trips for utilitarian and leisure motives. The design is evaluated by connectivity indicators used to describe the design dimension in most walkability indexes. Streetscape features are based on the five urban design qualities of Imageability, Enclosure, Complexity, Transparency and Human Scale that are important for the perception of the urban environment (Stefansdottir 2018) crucial for walking behaviour. Streetscapes characteristics are measured by these indicators defined and operationalized by Ewing and Purciel. We tested and operationalised the indicators from existing literature, developing new methodologies to measure streetscape characteristics using 3D models.

Finally, it was compared the power of different connectivity measures and street scape characteristics to explain walking behaviour for leisure and utilitarian purposes, using linear regression models.

Background

Travel behaviour has been extensively studied in recent years. Concerns about sustainable development and the impact of mobility options on climate change and air quality, which exacerbate public health risks, lead to an increased interest in active travel. Changes on built environment that support walking have been measured by concepts like walkability (Frank et al. 2005; Saelens and Handy 2008). However, the indicators and methods to measure the walkability conditions that shapes walking behaviour is not consensual.

The city design and the way it is planned define the city's overall structure. This structure comprises streets, blocks, buildings and other major infrastructure *(Rynning 2018)*. The structure of the city is planned at a city level or metropolitan level, and it hardly changes across time. On the other hand, public space defined by this overall structure, can foster different qualities and levels of attractiveness (Kim, Park, and Lee 2014). The pedestrian or citizen level, that requires evaluation in a smaller scale but higher level of detail, is defined by several authors as the human scale of the city (Stefansdottir 2018; Jacobs 1963; Lynch 1960). These two levels and scales of the city characteristics differently influence walking travel and different walking motives.

In the research of travel behaviour, several aspects of the built environment were identified as important to influence modal choices. Rynning (2018) categorized three elements that determine conditions to modal choice and mobility behaviours for urban travels: urban structure, land use, and mobility systems at the city scale. The neighbourhood scale introduces a fourth category, urban features (Rynning 2018). The first three dimensions, urban structure, land use, and mobility systems, are highly interrelated and interdependent. Changing one will influence the remaining two, which can induce a shift in mobility patterns. The extent of travel pattern that changes will depend on the context and the significance of the change (Rynning 2018).

The urban structure is the most immutable dimension of the city and remains more or less the same through time. One way to evaluate the influence of urban structure on travel behavior is based on D dimensions. According to the Ewing and Cervero (2010) the travel behavior is influenced by density, diversity and Design of the city. For Rynning (2018), the first three D's result from urban structure, land use, and the organization of the mobility infrastructure. The urban structure defined by Rynning (2018) matches the design dimension in the Cervero (2010)'s D dimensions. This dimension is frequently determined by connectivity measures. In fact, in a literature review one out of the four types of methodologies identified to evaluate active accessibility (Authors 2016), is entirely focused on the topological aspects of the built environment, utilizing methodologies like Space Syntax and different connectivity measures. Moreover, in the remaining three groups of methodologies the design dimension is frequently described using connectivity indicators.

The walkability literature reports two main approaches to measuring **the Design dimension**. One seeks to measure the connectivity of the pedestrian network (Fonseca et al., 2021; Authors, 2016), and this approach is commonly used in most walkability indexes that use objective data. A highly-connected network minimizes distances between different points in the overall network, and increases the number of alternative routes for a pedestrian. On the other hand, a poorly-connected network has a tree-like structure, with many cul-de-sacs; here the difference between the actual walking distance and the as-the-crow-flies distance is high (Boeing 2018; Pafka and Dovey 2017; Ellis et al. 2016; Ozbil et al. 2019). Studies that have developed aggregate walkability indexes often report that connectivity is twice as influential as the other dimensions, illustrated by the walkability index developed by Frank et al. (2010). Nevertheless, this is not always the case. For instance, the evaluation of walkability reported in Grasser et al. (2017) gives the same weight to all dimensions. In either case, it should be noted that connectivity is insufficient to account for the complexity of walking conditions perceived at street level, as it ignores features that make a route attractive and interesting for pedestrians (Ellis et al. 2016).

In fact, the walking movement has a biological dimension, and it is intimately related with the biological and individual's sense of the place. For pedestrians, human scale is crucial, since at this distance the pedestrian can see details, touch signs and use the sense of smell (Hillnhütter 2022). Different authors define the human scale conditions as the atmosphere of public spaces, and this has an important role in encouraging active transport, social contact or other health promoting behaviour (Hillnhütter 2022). The five qualities identified as important to this atmosphere and as determinants of walkability which are Imageability, Enclosure, Human scale, Transparency, and Complexity (Ewing and Handy 2009), were later expanded to include Legibility, Linkage and Coherence (Ewing and Clemente 2013). The evaluation of urban street features using these qualities requires onsite data collection, usually obtained through street audits (Millstein et al. 2013; Su et al. 2019; Cain et al. 2017). Trained auditors visit street segments and evaluate predefined features that influence the eight urban design qualities. Several protocols define the methods and characteristics to be collected by trained auditors. Of these, the protocol defined by Ewing and Clemente (2013) is used most often. The method identifies 51 streetscape characteristics deemed relevant for walking, and operationalizes them as measures of the five initial determinants of walkability (Imageability, Enclosure, Human scale, Transparency, and Complexity).

The five determinants of walkability act mostly on the individual perception of built environment. In fact, these perceptions have a higher influence on walking as a modal choice than other types of travel modes. The influence of the built environment also depends on the individuals' personal context (Hillnhütter 2022). Moreover, the built environment characteristics also influences the individual perception of itself, their socio-economic conditions and the notion of happiness and well-being (Kyttä et al. 2016; Stefansdottir 2018; Jiao et al. 2016). This influences reenforce the importance of urban design qualities beyond a well-connected road network to the promotion of individual wellbeing.

The main problem with measuring urban design qualities is that data collection is resource-intensive, which not only increases costs, but also limits the ability to compare regions. In order to overcome this limitation, Purciel et al. (2009) developed a set of GIS measures to evaluate the five urban design qualities proposed by Ewing and Handy (2009). Significant correlations were found between results obtained using these GIS indicators, and those obtained from a conventional urban audit. More recently, Yin (2017) introduced a set of tridimensional indicators to evaluate the same five qualities. The author developed walkability indicators using a variety of data sources, including audits, Google Street View images, and GIS measures. The study found a significant correlation between the new indicators and the number of pedestrians.

Still, the relative contribution of the connectivity characteristics and streetscape features for walking trips is not clear. This is an important point, as it is more-or-less feasible to improve the built environment at different scales. Changes on urban features are easier and cheaper to implement, while it is difficult to change the urban form of a neighborhood (Cambra and Moura 2020; Steinmetz-Wood, El-Geneidy, and Ross 2020; Kim, Park, and Lee 2014).

Regardless of the use of connectivity measures or streetscapes features, it is well-known that the impact of urban characteristics on travel is a function of the trip's purpose (Van Dyck et al. 2013), which can be classified into two main groups: utilitarian and leisure. As these two types of trips differ substantially in terms of duration, frequency, and distance, (Yang and Diez-Roux 2012; Steinmetz-Wood, El-Geneidy, and Ross 2020), it is interesting to investigate the different influence that the built environment has on them. For example, the literature suggests that leisure trips are highly influenced by the availability of private recreational facilities, and their characteristics (Giles-Corti et al. 2005; Steinmetz-Wood, El-Geneidy, and Ross 2020; Saelens and

Handy 2008). In contrast, utilitarian trips are mostly influenced by the proximity of the destination, and the public transport supply (Kang et al. 2017). Research concluded that over 90% of public transport journeys include at least two walking trips (Hillnhütter 2022). Additionally, research shows that the network layout (connectivity) influences access to transit stop by shaping the catchment area. The type of urban structure determines which sections of the catchment area are actually accessible by foot.

Materials and methods

Case study

The context of this study is Santarém. This low-density, medium-sized Portuguese city (106.05 habitants/Km^2)(PORDATA 2021) has been shaped by a particular topography ([Figure 1). The historical center is located on a plateau that is at a higher altitude than the more recent urban development. Because of this key characteristic, the analysis was restricted to the city center in order to control for the impact of the topography on walking behavior. [Figure 2 illustrates some of street characteristics of the study area. The medium sized cities context has complex challenges for active travel, related with the lack of public transport and the uncomplicated car use (low traffic and parking availability). This is particularly important because in Portugal small and medium-sized cities constitute a total of 121 cities, where 1.8 million inhabitants reside (17% of total population) (Authors. 2018). The novelty of this context requires the testing of several indicators suggested on literature. This justifies the test of different density, diversity, design, and accessibility measures on the statistical modelling.

[Figure 1 here].

[Figure 2: here].

Data collection

The scale of analysis is the 740 street segments defined by the topological rules used to create a network. The segments are located in the historical centre of Santarém. The study only uses quantitative and objective data, collected from different sources, including on the field collection.

Walking trip data were collected through a survey that was run in the context of the (xxxx)[1] project with goal to evaluate the impact of built environment on travel behavior. The survey collects individuals' socio-economic information, travel options (car ownership, public transport tickets, etc.), and daily trip diary.

Following the most relevant literature, data were aggregated per street segment rather than taking whole streets as units of evaluation (Taleai and Taheri Amiri 2017). Indicators were measured for each building, then averaged for each street segment. Setback distances were measured from the entrance of the building that was closest to the street segment. If there were no buildings on a segment, endpoints, and the midpoints of the segments were used as base-points to evaluate 3D characteristics of street segments, rather than points closest to the buildings on each street.

Urban Structure the Ds approach

[Table 1 describes variables utilized in the evaluation of each dimension for the 740 street segments. Most data were calculated using ArcGIS toolboxes previously developed for the xxx study, evaluated for a 500m buffer from each building, then aggregated as described above. A distance of 500m is typically used to define the bespoke neighbourhood, which has the highest

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[1] More information can be found at (xxxxxxx)

influence on daily activity, including walking (Learnihan et al. 2011). Each dimension was captured by several indicators that were analysed to evaluate their contribution to walking behaviour to the specific context of Santarém, a medium sized city. The indicators are described in detail below.

[Table 1: Variables and descriptive statistics, here].

Density

Density, especially population density, influences the availability of transport infrastructures and the number of services and facilities (Rynning 2018; Forsyth et al. 2007). The design of the city influences density values, not only on population density, but also on the number of buildings and activities. In that way, five types of density were evaluated, ranging from housing density (*Dens1*) to overall building density (*Dens2*) and the density of activities (*Dens5*).

Diversity

The density of population and activities can lead for a more diversity of activities and services (Rynning 2018; Forsyth et al. 2007). However, this may not be true for the medium sized cities context. To test this assumption, four diversity indicators are calculated based on detailed maps of building footprints and types of activity. The percentage of single-family buildings (*Div1*) describes the area occupied by detached houses. The percentage of residential buildings (*Div2*) captures all housing. *Div3* captures the non-residential percentage of the area. Finally, the mixed-use indicator (*Div4*) evaluates the mixture of uses dedicated to different activities.

Design - connectivity measures

The structure design of the city defines the space distribution for the public and private space, and it has been measured by several connectivity measures (Authors 2016). Connectivity measures evaluate the road centerline network and include four indicators. The first is node density (*Con1*), which represents the density of nodes with more than three links within the 500m network buffer. The second is the pedestrian shed ratio (*Con2*). This calculates the difference between the area defined by the 500m circular buffer and the pedestrian catchment area (calculated with ArcGIS Network Analyst 10.6). Straightness (*Con3*) considers the distance that can be covered, as the crow flies, within the 500m buffer. Mean link length (*Con4*) evaluates the length of street segments in the road network, for all segments in the buffer.

Accessibility

Accessibility to activities is important for the individual daily routine. Moreover, public transport is important destination as part of a trip sequence. All the trips start with a walking trip, and this is especially important for public transport trips. Following this assumption, accessibility to activities and public transport infrastructure were measured. The distance to the closest transit stop (*Acc1*) captures the distance in meters to the closest bus stop. *Acc2* evaluates the daily public transport supply at the closest transit stop. *Acc3* evaluates total public transport supply in the 500m buffer. *Acc4* captures the distance to the closest activity. *Acc5* is the mean distance to the three closest activities. *Acc6* is the number of activities within the 500m meter buffer. Finally, *Acc7* evaluates commercial continuity. This was assessed as the number of activities in the network, divided by the network distance. A more detailed description of these methods, including the ArcGis toolbox that was developed to calculate indicators, is available from the XXXX project's website[2].

Walking trips

The dependent variable was the number of walking trips passing through streets in the study area.

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[2] xxxxxx

Walking trips were obtained through a travel survey of 1100 individuals (over 16 years old) living in Santarém. This survey captured walking trips, lasting over five minutes, made the previous working day (Monday and Friday were excluded, as trip patterns differ on these days, due to, for example, students returning home from studying outside the city). Trips were measured door-to-door, and the survey was run in May 2013, thereby capturing mobility during a normal working/school week in mild weather. Interviewees reported the origin and destination of their trip, and its motive. Routes were estimated using ArcGIS Network Analyst 10.6, selecting the shortest option. Motives were subdivided into eight general groups, which were then classified as utilitarian or leisurely. Utilitarian trips included travel to work or school and back, chauffeuring other family members, and travel to meals because many individuals go home to have lunch. Outings for personal reasons were also considered as utilitarian trips. Leisure travel included shopping or recreation, along with outings for exercise, including running and walking. A total of 1788 trips were recorded. Most were utilitarian, 1344 (75%), and only 444 (25%) were for leisure.

Urban design qualities

As described previously, urban street features are very important to walking because they influence the individual perception of the built environment attractiveness (Kim, Park, and Lee 2014). The paper does not evaluate individual perception, instead, it evaluates the streetscape feature that can shape this perception. The streetscape feature important for individual perception was systematized in five dimensions by Ewing and Handy (2009) and it includes *Imageability*, *Enclosure*, *Human scale*, *Transparency*, and *Complexity*. *The five dimensions proposed organize different* streetscapes features and several authors developed methods and tools to evaluate it, including on site collections, surveys, and, more recently, automated image classification.

The streetscape features evaluation was built on the audit protocol assessment defined in the Ewing and Handy (2009) study. The evaluation of the streetscape features was made using the five dimensions of this protocol, and extends the work of Purciel et al. (2009) and Yin (2017), with some modifications that are described in the following sections. Table 2 systematizes the proposed indicators in Ewing and Handy' work (2009).

[Table 2: Streetscape features given in Ewing and Handy (2009), here]

Number of courtyards, parks and plazas on the block face

Ewing and Handy (2009) measured this indicator by counting the number of courtyards, plazas or parks with a side that faced each unit block. In this paper, GIS data was used to calculate the total area covered by parks and green spaces (in m^2) within the 500m catchment area of each building and took the mean per street segment.

Proportion of historic building frontage

Ewing and Handy (2009) measured this indicator by dividing the total length of the historic building frontage (pre-World War II buildings) by the total length of each block face. The 2011 Census records the total number of pre-1945 buildings on a per-block basis; consequently, it was used the mean number of buildings in neighboring blocks per building-point, then calculated the mean for each street segment.

Number of buildings with identifiers

Ewing and Handy (2009) define this measure as the number of buildings, per block face, with a sign indicating their use. In the present research it was used point-of-interest information provided by the city council (recorded in the XXXX project's database) and identified uses that commonly require signage (e.g., stores, cafes, and bars), but excluded other activities such as schools, vacant stores, and administrative functions. This method gave the number of buildings with identifiers for each street segment.

Proportion of street wall

Ewing and Handy (2009) measured the proportion of street wall as the total length of block face taken up by buildings or other boundary elements, divided by the length of the block. The present paper used the length of building edges that touched the sidewalk and remained within a changing buffer for each street segment. An additional 3.5m was added to the buffer (the distance from the closest building edge to the street segment), as this distance is considered to be the maximum within which visual and social interaction between the building's inhabitants and people in the street is possible (Gehl 1987). The result is the percentage of each segment adjacent to boundary elements (see [Figure).

[Figure 3: Proportion of street wall calculation, here]

Mean building height

Ewing and Handy (2009) defined this measure as the approximate height of each building, calculated by multiplying the number of floors per building by the mean height of each block face. For the present paper, it was calculated building height by multiplying the number of floors by 3.5, but did not weigh each building's height value based on its facade length. The value for the street segment was calculated as the mean height of all buildings in the segment.

Facades with windows to total facade proportion

Ewing and Handy (2009) made a visual estimate of the percentage of facades with windows compared to the total facade area on the ground floor of buildings, per block face. Like buildings with an identifier, buildings that were likely to have facades were determined. Their total length was divided by the total of all building facade lengths per street segment. The result is the percentage of the street segment occupied by windows (see [Figure).

[Figure 4: Calculation of the proportion of building facades (authors), here].

Total number of buildings per block face

It was computed the number of buildings with direct access to each street segment.

Visibility of major landscape features

This measure requires counting all landscape features when walking along the street; examples include mountains, water bodies, or greenery. For this measure, a 3D digital model of the city was used. Starting from building access points from each street segment, eye-level points were created by elevating them to 1.5m above ground. Then it was used a ray casting method to send rays to grids of points on landscape elements such as the green areas and the Tagus river. Based on the unobstructed rays reaching each landscape element, the number of landscape elements visible from each point were computed. Finally, it was calculated mean values for all points, per street segment (Figure 5).

[Figure 5: Model to calculate the visibility of major landscape features, here].

Proportion of visible sky

Ewing and Handy's (2009) method require the auditor to estimate the percentage of visible sky in three directions, from several points along a block face, in their frame of view. Again utilizing the 3D city model, it was created a view frame in four directions that was 168m from points of view that were 1.5m above ground, to simulate eye level, for each building point, following the criteria of Purciel et al (2009). The next step was casting rays to a grid of points in the view frame and calculating the percentage of rays that were not interrupted by buildings or topography (see [Figure).

[Figure 6: Model to calculate the proportion of visible sky, here]

Number of long sightlines

In Ewing and Handy's method (Ewing and Handy 2009), the auditor is directed to look in three directions from several points along a block face, and count the instances where the sightline is uninterrupted. Using 3D model, 300m rays were sent out in four directions from the building base points at 1.5m above ground level and counted instances where they were not interrupted by buildings or topography (see [Figure).

[Figure 7: Number of long sightlines, here].

Number of buildings with non-rectangular shapes

The buildings footprints were used to capture non-rectangular buildings. Furthermore, it was assumed that buildings with more than six vertices on the facade had a non-rectangular shape. The present paper approach takes into account the fact that facades of one building can be different on different streets (see [Figure).

[Figure 8: Method to identify non-rectangular buildings (authors), here]

Statistical analyses

Descriptive statistics for all considered indicators and dimensions are presented on [Table 1. Motives for walking were tested using a multiple regression analysis based on models of utilitarian and leisure trips. The regression models to explain the walking trips was tested with three models: one using connectivity measures, another for using streetscape features measures by GIS and 3D indicators, and a third model, that combined all indicators. Multicollinearity was evaluated with the variance influence factor (VIF), adopting the assumption that values above 10 are problematic (Marôco 2010).

Results

All trips

Table 3 presents results for the three multiple linear regressions for all walking trips (1788) considering the three models.

The first model, using connectivity measures, explains 55% of the variance (adjusted $R^2 = 0.549$). Density, Diversity and Connectivity dimensions have variables that are significant at $p<0.001$. These results confirm the importance of the 3Ds dimensions (Density, diversity and design) and accessibility to explain walking behaviour, with statistically significant results for each dimension.

The second model which was based on streetscape features explained 48% of the variance (adjusted $R^2 = 0.483$), which is 7% less than the first model. The streetscape features, diversity and accessibility to public transport are found to be important indicators to explain walking trips.

The third model evaluated both connectivity and streetscape features. This model explained 60% of the variance (adjusted R^2=0.599), which is 5% higher than model one (the connectivity model) and 12% higher than model two (streetscape features). The joint model shows that all the considered dimensions have indicators significant to explain walking trips.

[Table 2: Multiple linear regression models – total walking trips (1788), here]

Utilitarian trips

Results for the three models of utilitarian trips (1344), which make up 75% of trips, are presented in [Table 3. Adjusted R^2 values are similar to the results for all trips. However, they are lower in the third model. Similarly, these values are lower in model two, compared to the same model for all trips. These changes suggest that streetscape features are less relevant in explaining utilitarian trips.

In model one, using connectivity measures, the coefficient values increase for Density indicators. In the Diversity dimension the indicator remain statistically significant, but values decrease compared to all trips. As for connectivity measures, the behavior is very similar to all trips. In the Accessibility dimension, statistically-significant variables are the same as for the overall sample.

In model two, using streetscape features, Housing Density is statistically significant (Div 1, β=0.137, *p*<0.001). The same is true for Diversity, concerning the percentage of single-family buildings (Div 1, β=0.191, *p*<0.001) on the diversity dimension. Results for the Accessibility dimension are similar to results for the overall sample.

In model three, for connectivity and streetscape features, Density and Diversity variables have a similar behaviour. For connectivity measures, results are similar to those for the overall sample. As for streetscape features, the pattern of results is similar to the overall sample. The major difference is the statistically significance for mean building height, (Dsg8, β=0.115, *p*<0.001). Finally, in the Accessibility dimension, values are very similar to results for all trips.

[Table 3: Multiple linear regression models – utilitarian trips (1344) here]

Leisure trips

The results of the models for leisure trips (444, 25%) are illustrated in [Table 4. The explanatory powers of the three models are quite different. The adjusted R^2 is lower than for all trips and utilitarian trips.

In model one, using connectivity measures, Diversity and the Connectivity values have a similar pattern with all trips. In Density dimension, the services and retail gross floor area ratio lose the statistical significance comparing with the utilitarian trips. The Accessibility dimension varies the most – from both the overall sample and utilitarian trips, with the reduction of coefficient values.

In the case of model two- streetscape features, unlike the overall sample, the different Density indicators are statistically significant. In the Diversity dimension, the urban complexity (*Div1*) remains statistically significant. Although values for the Accessibility dimension are similar to those for model one, they are clearly different from the same model for all trips and utilitarian trips. Here, coefficients are lower, and only the distance to the closest transit stop is statistically significant ($\beta = -0.424$, $p<0.001$).

In model three, using connectivity and streetscape features, the results for the Density, Diversity and Connectivity dimensions are similar to the entire sample. Within the Accessibility dimension, the distance to the closest transit stop remains the only statistically significant variable (*Acc1*) ($\beta = -0.339$, $p<0.001$).

[Table 4: Multiple linear regression models – leisure trips (444), here]

Discussion

The results show that the models using the connectivity indicators have a slightly higher adjusted R^2, than the models that use the streetscape indicators to explain walking utilitarian trips and walking trips in general. On other hand, the models combining the connectivity and streetscape indicators have a higher adjusted R^2 for the different trip purposes. Nevertheless, the different indicators have different importance considering the trip purposes.

Looking in detail at the differences between the impact of indicators in relation to trip motives, even though the overall pattern is similar, a slight difference can be identified with respect to leisure trips. Here, the coefficient values of density indicator decline, and the density of services loses the statistical significance. Moreover, accessibility measures become less important. Results for leisure trips highlight the reduced importance of service and retail density. Access to public transport is important for utilitarian trips, but less important for leisure trips.

Analyzing the three models and the two trip motives, the connectivity measures were found to be the most stable. Accessibility shows the greatest variance and is less significant with respect to leisure trips. The streetscape model has the lowest explanation power of the models, comparing with the connectivity measures and the combined indicators.

The results reinforce the significance of connectivity measures in explaining walking (Frank and Engelke 2001). Better connectivity increases walking route options, and expands the building frontage that can provide street-level activities (Sevtsuk, Kalvo, and Ekmekci 2016; Pafka and Dovey 2017). Nevertheless, the streetscape features are also important for the two walking motives, which are more influenced by perceived attributes than connectivity. Changing the streetscape is more feasible than altering the urban form, and it can have an impact on street appeal, thus increasing the number of people who walk (Steinmetz-Wood, El-Geneidy, and Ross 2020; Kim, Park, and Lee 2014; Erturan and van der Spek 2022). The evaluation of streetscape features and their impact on urban design qualities helps us to better understand the built environment, and can explain a significant amount of variance in walking behavior. Moreover, streetscape features are significantly different from connectivity measures, which raises the question of the validity of connectivity measures as a proxy for design qualities when evaluating walkability conditions. Finally, the streetscape can improve the quality of the urban environment and the walking experience, but appears to have a lesser influence on walking in general (Cambra and Moura 2020).

The results suggest that streetscape features have lesser influence on walking in general; however, their contribution to the quality of urban environment has an impact on individuals' walking experiences (Arellana et al. 2019; Kim, Park, and Lee 2014; Steinmetz-Wood, El-Geneidy, and Ross 2020; Hillnhütter 2022). This positive or negative experience defines individual travel satisfaction that contributes to the creation of captive users on different travel modes (De Vos et al. 2015; Mouratidis, Ettema, and Næss 2019). The satisfaction of the walking experience contributes to the maintenance of travel habits, especially for walking. Streetscape features play an important role in individual perception of built environments. The improvement of this streetscape's features can contribute to a better perception of built environment by creating higher street attractiveness. Nevertheless, these perceptions will depend on the individuals' personal context, which is defined by their past and personal conditions *(Hillnhütter 2022).*

Walking is crucial to achieve more sustainable modes of transportation, and a well-designed, planned, and connected city is fundamental to promote walking trips. The connectivity indicators provide a good description of this connected city that supports walking. However, streetscapes features provide more detailed characteristics that define the built environment atmosphere and characteristics, which contributes to individual emotions and wellbeing that remains unmeasurable (Hillnhütter 2022; Stefansdottir 2018). The characteristics of this urban atmosphere, created by the streetscape features, play a role in the citizens' perception of quality of life. A positive perception about their living environment supports their perceived health happiness and wellbeing (Kyttä et al. 2016) and contribute to their SES individual perceptions (Stefansdottir 2018; Jiao et al. 2016).

The results give an important contribution to the research by providing tools and methods to evaluate the streetscape features that influence individuals' perceptions. The application of the suggested tools can be made at different scales of analysis, identifying environment places that are more human and walking friendly and that support more sustainable, and generally healthier, modes of transportation. This evaluation can be used to define a strategic approach to promote the use of sustainable modes of transportation and individuals' wellbeing where there are worse built environment conditions, which present a higher risk of deprivation (Authors, 2023).

The proposed indicators and methods have a few limitations. First, these indicators do not capture data on individuals' perceptions for walking trips or travel satisfaction. Secondly, the indicators used do not evaluate aspects such as safety and security used in most of the audit measures found in the literature and that are important for specific groups and contexts (Arellana et al. 2019; Appleyard 2022). Thirdly, walking route data utilized are estimates based on the shortest routes between origin and destination points on the street network, rather than actual routes.

Nevertheless, the study offers some insights for further research. For example, future work could evaluate streetscape characteristics' capacity to predict perceptions, which can be tested with new virtual reality tools (Nakamura 2021). The results point to the importance of accessibility of public transport in increasing the number of people walking; however, quality of the trip experience was not evaluated the. This paper also provides insight on means to improve the walkability indices that are used extensively in literature. Particularly, it suggests the introduction of new indicators that can be used at different-scale evaluations.

Conclusion

In conclusion, the paper presents a new approach for the improvement of methods and indicators used in the evaluation of the built environment conditions that influence walking behavior. Firstly, it challenges the applicability of the theoretical model of Ewing and Handy (Ewing and Handy 2009) in a lower density and urban, Portuguese context. Secondly, through a case study, it is proposed that connectivity measures have greater explanatory power than models based on evaluating streetscape features. However, the joint evaluation of connectivity and streetscape performs best.

In this paper the importance of accessibility for walking is highlighted, especially for utilitarian trips. The results confirm the significance of the urban form assessed by connectivity measures, which are used in most of the walkability literature to explain trips with different motives. Nevertheless, the introduction of streetscape features into an evaluation can help in further explaining walking. The results emphasize the importance of the streetscape characteristics' influence on a range of walking activities; a finding particularly valuable given that it is easier to improve smaller-scale built environment features than changing the urban form.

The new measures enable the evaluation of indicators at different levels of analysis and without the requirement of on-site audits. Such approaches become more relevant as data regarding streetscape features relevant for measuring walkability of built environments become available for an expanding range of geographies every day. Future work could test the contribution of streetscape features to different walkability indices, using the newly proposed indicators. There is research yet to be done for validating walkability measures based on perceptual indicators such as safety, comfort and attraction, looking at walking as both a mode of travel and a recreational activity.

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Declaration of interest statement

The authors have no conflicts of interest to disclose.

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Table 1: Variables and descriptive statistics.

					Street Segments Descriptive statistics (N=740)				
Variable	**Description**	**Source**	**Year**	**unit**	**Min**	**Max**	**Mean**	***Skew***	***Kurtosis***
Density									
Dens1	Housing density (Dwellings per ha)	1)	2013	number	1.38	76.65	34.39	0.10	-0.19
Dens2	Building Density (Buildings per ha)	1)	2013	number	1.60	29.73	13.01	-0.07	-1.38
Dens3	Gross Floor Area Ratio (Index)	1)	2013	index	0.08	1.64	0.84	-0.27	-0.55
Dens4	Housing gross floor area ratio (Index)	1)	2013	index	0.03	0.93	0.46	0.21	-0.50
Dens5	Services and retail gross floor area ratio (Index)	1)	2013	index	0.00	0.79	0.38	0.09	-1.33
Diversity									
Div1	Percentage of single family buildings (% of buildings)	1)	2013	%	4.44	58.41	23.03	1.50	2.87
Div2	Percentage of residential dwellings (% of dwellings)	1)	2013	%	43.61	95.54	70.75	-0.15	-1.35
Div3	Percentage of area occupied by activities (% of area of each activity)	1)	2013	%	0.04	17.83	7.57	0.37	-1.26
Div4	Urban complexity (Index ≥ 0)	1)	2013	index	1.81	2.65	2.45	-0.82	5.88
Design - Connectivity									
Con1	Node density (Nodes per ha)	1)	2013	number	0.26	4.15	2.37	-0.11	-0.77
Con2	Pedestrian shed ratio (Index]0-1])	1)	2013	index	0.12	0.67	0.44	-0.53	-0.28
Con3	Straightness (ratio)	1)	2013	ratio	0.54	0.96	0.75	-0.51	1.24
Con4	Average link length (meters)	1)	2013	meters	33.81	99.01	46.16	1.40	2.52
Design - Streetscape features									
Dsg1	Mean of square meter of green spaces for each building in segment	1)	2013	meters	0.00	26866.02	8742.09	0.79	-0.32
Dsg2	Mean of long sight line views of major landscape for segment	1)	2013	number	0.00	3.00	0.38	1.71	3.18
Dsg3	Mean of buildings constructed before 1945	2)	2011	%	0.00	100.00	27.39	0.85	-0.51
Dsg4*	Sum of the number of buildings with identifier in each segment	1)	2013	number	0.00	7.75	0.94	1.43	3.97
Dsg5	Percentage of rays not interrupted by buildings of topography (Proportion sky)	1)	2013	%	0.00	1.00	0.16	0.94	0.88
Dsg6	Proportion of segment surrounded by walls	1)	2013	%	0.00	100.00	75.28	-1.09	-0.22
Dsg7	Average of uninterrupted view to major landscape	1)	2013	number	0.00	6.00	0.83	1.79	3.44
Dsg8	Mean building height for each segment	1)	2013	meters	0.00	31.50	10.50	1.40	1.19
Dsg9	Proportion of segment occupied by activities with windows	1)	2013	%	0.00	100.00	23.86	1.28	0.44
Dsg10*	Total of buildings in each segment	1)	2013	number	1.00	6.32	1.96	1.55	3.85
Dsg11	Number of building with non-rectangular shape	1)	2013	number	0.00	7.00	1.09	1.18	1.19
Acessibility									
Acc1	Distance to the closest transit stop (meters)	1)	2013	meters	10.51	1085.02	363.34	0.63	-0.24
Acc2	Transit supply in the closest transit stops (total supply per day)	1)	2013	number	20.00	133.00	84.22	-0.64	-0.10
Acc3	Transit frequency (Supply per day by public transit stop)	1)	2013	number	0.00	107.67	32.76	0.58	-0.68
Acc4	Distance to the closest activity (meters)	1)	2013	meters	0.01	602.72	79.46	2.46	7.52
Acc5	Average distance to 3 closest activities (meters)	1)	2013	meters	4.43	609.08	104.90	2.24	6.09
Acc6	Number of activities (integral number)	1)	2013	number	7.50	1520.67	598.12	0.45	-1.31
Acc7	Commercial continuity (number of activities per 100m)	1)	2013	number	0.43	11.43	6.30	-0.02	-1.52
Walking									
WalkT*	Total shortest walking trips	3)	2013	number	0.00	18.81	5.78	0.65	0.20
WalkU*	Total shortest walking trips for utilitarian purposes	3)	2013	number	0.00	16.91	4.93	0.74	0.60
WalkL*	Total shortest walking trips for leisure purposes	3)	2013	number	0.00	11.58	2.88	0.79	0.93

* Square root transformation

1) Authors using CM Santarém Data; **2)** Instituto Nacional de Estatística, population census 2011; **3)** Survey

Table 2: Streetscape features given in Ewing and Handy (2009).

Urban design qualites and streetscapes features defined by Ewing, & Handy (2009)	**Source**	**Code**	**present study**
Imageability			
Number of parks, courtyards and plazas on the block face	Green areas - Project Data base	1	GIS
Number of major landscape features	Green areas - Project Data base, Open street maps	2	3d model
Proportion of historic building frontage	2011 CENSUS data (Construction year)	3	GIS
Number of buildings with identifier	Activities - Project Data base	4	GIS
Number of buildings with non-rectangular shapes	Buildings footprints - Project Data base	5	GIS
Presence of outdoor dining	-	6	not calculated
Number of people	Survey - Project Data base	7	Survey
Noise level	-	8	not calculated
Enclosure			
Number of long sight lines visible in three directions	3D model including the data of major landscape features	9	3d model
Proportion of street segment with street wall (observer side of street)	Activities - Project Data base	10	GIS
Proportion of street segment with street wall (opposite side of street)	Activities - Project Data base	11	GIS
Proportion sky (ahead, beyond study area)	3D model	12	3d model
Proportion sky (across, beyond study area)	3D model	13	3d model
Human Scale			
Number of long sight lines visible in three directions	3D model	9	3d model
Proportion of street segment with windows (observer side first floor building facade)	Activities - Project Data base	14	GIS
Proportion of street segment with active uses (observer side of street)*	Activities - Project Data base	18	GIS
Average height of buildings weighed by building frontage (observer side of street)	Buildings footprints and height - Project Data base	15	GIS
Number of small planters (observer side of the street)	-	16	not calculated
Number of pieces of street furniture	-	17	not calculated
Transparency			
Proportion of street segment with windows (observer side first floor building facade)	Activities - Project Data base	14	GIS
Proportion of street segment with street wall (observer side of street)	Activities - Project Data base	10	GIS
Proportion of street segment with active uses (observer side of street)	Activities - Project Data base	18	GIS
Complexity			
Number of buildings (both sides of street)	Buildings footprints - Project Data base	19	GIS
Number of basic building colours (both sides of street)	-	20	not calculated
Number of accent building colours (both sides of street)	-	21	not calculated
Presence of outdoor dining (observer side of street)	-	6	not calculated
Number of pieces of public art (both sides of street)	-	22	not calculated
Number of people (observer side of street)	Survey - Project Data base	7	Survey

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Table 3: Multiple linear regression models – total walking trips (n=1788).

			Model 1				**Model 2**				**Model 3**			
			Connectivity				**Streetscape features**				**Connectivity & Streetscape**			
Dimension		**Type**	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***
Density														
Dens1	Housing density (Dwellings per ha)	GIS	0.114	0.008	0.427 ***	1.534	0.040	0.011	0.149 ***	2.578	0.085	0.011	0.321 ***	2.873
Dens5	Services and retail gross floor area ratio (Index)	GIS	-4.048	0.940	-0.222 ***	4.345	0.864	1.076	0.047	4.959	-2.293	1.058	-0.126 *	6.184
Diversity														
Div1	Percentage of single family buildings (% of buildings)	GIS	0.053	0.012	0.128 ***	1.467	0.086	0.014	0.209 ***	1.654	0.065	0.012	0.157 ***	1.679
Div4	Urban complexity (Index ≥ 0)	GIS	1.749	1.358	0.046	2.093	-1.483	1.463	-0.039	2.116	1.608	1.332	0.042	2.262
Div2	*Percentage of residential dwellings (% of dwellings)*	GIS												
Design - Connectivity														
Con2	Pedestrian shed ratio (Index]0-1])	GIS	12.914	1.615	0.371 ***	3.522					12.040	1.747	0.345 ***	4.625
Con3	Straightness (ratio)	GIS	16.395	2.375	0.240 ***	1.982					16.244	2.387	0.238 ***	2.249
Design - Streetscape features														
Dsg1	Mean of square meters of green spaces for each building in segment	GIS					0.000	0.000	-0.056	2.926	0.000	0.000	-0.128 ***	2.999
Dsg2	Mean of long sigh line views of major landscape for segment	3D					0.164	0.274	0.024	2.407	0.064	0.242	0.010	2.414
Dsg3	Mean of buildings constructed before 1945	GIS					-0.002	0.006	-0.016	2.530	-0.011	0.005	-0.077 *	2.659
Dsg4*	Sum of the number of buildings with identifier in each segment	GIS					0.851	0.140	0.224 ***	1.921	0.782	0.124	0.205 ***	1.941
Dsg5	Percentage of rays not interrupted by buildings of topography (Prop. sky)	3D					-0.987	1.590	-0.032	3.883	0.618	1.439	0.020 *	4.101
Dsg6	Proportion of segment surrounded by street wall	3D					-0.002	0.004	-0.015	1.991	-0.002	0.004	-0.014	1.999
Dsg7	Average of uninterrupted view to major landscape	3D					-0.153	0.143	-0.043	2.292	-0.066	0.126	-0.019	2.304
Dsg8	Mean building height for each segment	GIS					0.089	0.020	0.166 ***	2.022	0.053	0.018	0.098	2.067
Dsg9	Proportion of segment surrounded by buildings windows of activities	GIS					0.004	0.004	0.036	1.854	0.000	0.004	0.002	1.877
Dsg10*	Total of buildings in each segment	GIS					-0.214	0.143	-0.047 **	1.427	0.038	0.132	0.008	1.563
Dsg11	Number of buildings with non-rectangular shape	GIS					0.336	0.101	0.107 ***	1.493	0.082	0.091	0.026	1.551
Accessibility														
Acc1	Distance to the closest transit stop (meters)	GIS	-0.007	0.001	-0.429 ***	2.603	-0.008	0.001	-0.483 ***	3.127	-0.098	0.013	-0.382 ***	4.048
Acc2	Transit supply in the closest transit stops (total supply per day)	GIS	-0.012	0.004	-0.084 **	1.278	-0.009	0.005	-0.065 **	1.428	-0.287	0.067	-0.133 **	1.436
Acc3	Transit frequency (Supply per day by public transit stop)	GIS	-0.002	0.004	-0.013	1.865	-0.008	0.005	-0.059	1.974	0.043	0.072	0.022	2.016
Acc4	Distance to the closest activity (meters)	GIS	-0.006	0.002	-0.135 ***	1.996	-0.005	0.002	-0.118 **	2.359	-0.027	0.027	-0.041 *	2.437
R^2			0.555				0.496				0.610			
Adjusted R^2			0.549				0.483				0.599			
F- Ratio			91.069***				37.274***				53.483***			
Df			10.000				19.000				21.000			

*p<0.05; **p<0.01; ***p<0.000

Table 4: Multiple linear regression models – utilitarian trips (n=1344).

			Model 1				Model 2				Model 3			
			Struture				Infrastructure				Struture & Infrastructure			
Dimension		**Type**	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***
Density														
Dens1	Housing density (Dwellings per ha)	GIS	0.100	0.007	0.428 ***	1.534	0.032	0.010	0.137 **	2.578	0.072	0.009	0.307 ***	2.873
Dens5	Services and retail gross floor area ratio (Index)	GIS	-4.183	0.831	-0.261 ***	4.345	0.346	0.952	0.022	4.959	-2.322	0.941	-0.145 *	6.184
Diversity														
Div1	Percentage of single-family buildings (% of buildings)	GIS	0.039	0.011	0.107 ***	1.467	0.069	0.012	0.191 ***	1.654	0.050	0.011	0.139 ***	1.679
Div4	Urban complexity (Index ≥ 0)	GIS	1.782	1.201	0.053	2.093	-1.186	1.295	-0.036	2.116	1.558	1.184	0.047	2.262
Div2	*Percentage of residential dwellings (% of dwellings)*	GIS												
Design - Connectivity														
Con2	Pedestrian shed ratio (Index]0-1])	GIS	10.697	1.428	0.350 ***	3.522					10.187	1.553	0.333 ***	4.625
Con3	Straightness (ratio)	GIS	14.684	2.100	0.245 ***	1.982					14.562	2.122	0.243 ***	2.249
Design - Streetscape features														
Dsg1	Mean of square meters of green spaces for each building in segment	GIS					0.000	0.000	-0.059	2.926	0.000	0.000	-0.130 **	2.999
Dsg2	Mean of long sigh line views of major landscape for segment	3D					0.110	0.243	0.019	2.407	0.026	0.215	0.004	2.414
Dsg3	Mean of buildings constructed before 1945	GIS					-0.005	0.005	-0.040	2.530	-0.012	0.005	-0.099 **	2.659
Dsg4*	Sum of the number of buildings with identifier in each segment	GIS					0.662	0.124	0.198 ***	1.921	0.604	0.110	0.181 ***	1.941
Dsg5	Percentage of rays not interrupted by buildings of topography (Prop. sky)	3D					-0.761	1.407	-0.028	3.883	0.577	1.279	0.022	4.101
Dsg6	Proportion of segment surrounded by street wall	3D					-0.001	0.004	-0.011	1.991	-0.001	0.003	-0.011	1.999
Dsg7	Average of uninterrupted view to major landscape	3D					-0.144	0.126	-0.046	2.292	-0.067	0.112	-0.021	2.304
Dsg8	Mean building height for each segment	GIS					0.086	0.018	0.182 ***	2.022	0.054	0.016	0.115 ***	2.067
Dsg9	Proportion of segment surrounded by buildings windows of activities	GIS					0.003	0.004	0.031	1.854	0.000	0.004	-0.002	1.877
Dsg10*	Total of buildings in each segment	GIS					-0.159	0.126	-0.040	1.427	0.053	0.117	0.013	1.563
Dsg11	Number of buildings with non-rectangular shape	GIS					0.248	0.089	0.090 **	1.493	0.027	0.081	0.010	1.551
Accessibility														
Acc1	Distance to the closest transit stop (meters)	GIS	-0.007	0.001	-0.440 ***	2.603	-0.007	0.001	-0.486 ***	3.127	-0.006	0.001	-0.422 ***	4.048
Acc2	Transit supply in the closest transit stops (total supply per day)	GIS	-0.013	0.004	-0.103 ***	1.278	-0.011	0.004	-0.084 **	1.428	-0.013	0.004	-0.103 ***	1.436
Acc3	Transit frequency (Supply per day by public transit stop)	GIS	-0.002	0.004	-0.016	1.865	-0.007	0.004	-0.061	1.974	0.001	0.004	0.008	2.016
Acc4	Distance to the closest activity (meters)	GIS	-0.005	0.001	-0.136 ***	1.996	-0.005	0.002	-0.127 **	2.359	-0.004	0.001	-0.090 *	2.437
R^2					0.549				0.488				0.600	
Adjusted R^2					0.543				0.474				0.589	
F- Ratio					88.773***				36.095***				51.332***	
Df					10.000				19.000				21.000	

*p<0.05; **p<0.01; ***p<0.000

Table 5: Multiple linear regression models – leisure trips (n= 444).

			Model 1				Model 2				Model 3			
			Connectivity				Streetscape features				Connectivity & Streetscape			
Dimension		**Type**	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***	**B**	**SE**	**β**	***VIF***
Density														
Dens1	Housing density (Dwellings per ha)	GIS	0.056	0.005	0.391 ***	1.534	0.027	0.006	0.189 ***	2.578	0.049	0.006	0.346 ***	2.873
Dens5	Services and retail gross floor area ratio (Index)	GIS	-0.830	0.520	-0.085	4.345	1189.000	0.576	0.122 *	4.959	-0.537	0.584	-0.055	6.184
Diversity														
Div1	Percentage of single family buildings (% of buildings)	GIS	0.041	0.007	0.188 ***	1.467	0.055	0.008	0.249 ***	1.654	0.044	0.007	0.202 ***	1.679
Div4	Urban complexity (Index ≥ 0)	GIS	-0.051	0.751	-0.002	2.093	-1.249	0.783	-0.062	2.116	0.075	0.735	0.004	2.262
Div2	*Percentage of residential dwellings (% of dwellings)*	GIS												
Design - Connectivity														
Con2	Pedestrian shed ratio (Index]0-1])	GIS	7.275	0.893	0.391 ***	3.522					6.553	0.963	0.352 ***	4.625
Con3	Straightness (ratio)	GIS	43.396	12.032	0.148 ***	1.982					6.562	1317.000	0.180 ***	2.249
Design - Streetscape features														
Dsg1	Mean of square meters of green spaces for each building in segment	GIS					-0.009	0.000	-0.033	2.926	-0.025	0.000	-0.092 ***	2.999
Dsg2	Mean of long sigh line views of major landscape for segment	3D					0.149	0.147	0.042	2.407	0.096	0.134	0.027	2.414
Dsg3	Mean of buildings constructed before 1945	GIS					0.003	0.003	0.039	2.530	-0.002	0.003	-0.022	2.659
Dsg4*	Sum of the number of buildings with identifier in each segment	GIS					0.547	0.075	0.269 ***	1.921	0.508	0.068	0.250 ***	1.941
Dsg5	Percentage of rays not interrupted by buildings of topography (Prop. sky)	3D					-0.755	0.851	-0.046	3.883	0.178	0.794	0.011	4.101
Dsg6	Proportion of segment surrounded by street wall	3D					-0.002	0.002	-0.027	1.991	-0.002	0.002	-0.025	1.999
Dsg7	Average of uninterrupted view to major landscape	3D					-0.056	0.076	-0.030	2.292	-0.019	0.070	-0.010	2.304
Dsg8	Mean building height for each segment	GIS					0.026	0.011	0.093 *	2.022	0.009	0.010	0.031	2.067
Dsg9	Proportion of segment surrounded by buildings windows of activities	GIS					0.003	0.002	0.052	1.854	0.001	0.002	0.019	1.877
Dsg10*	Total of buildings in each segment	GIS					-0.148	0.077	-0.061	1.427	-0.010	0.073	-0.004	1.563
Dsg11	Number of buildings with non-rectangular shape	GIS					0.225	0.054	0.135 ***	1.493	0.104	0.050	0.062 **	1.551
Accessibility														
Acc1	Distance to the closest transit stop (meters)	GIS	-0.003	0.000	-0.358 ***	2.603	-0.004	0.000	-0.424 ***	3.127	-0.003	0.000	-0.339 ***	4.048
Acc2	Transit supply in the closest transit stops (total supply per day)	GIS	0.000	0.002	-0.003	1.278	0.001	0.002	0.014	1.428	0.000	0.002	-0.005	1.436
Acc3	Transit frequency (Supply per day by public transit stop)	GIS	-0.001	0.002	-0.009	1.865	-0.004	0.003	-0.054	1.974	0.001	0.002	0.009	2.016
Acc4	Distance to the closest activity (meters)	GIS	-0.003	0.001	-0.127 ***	1.996	-0.002	0.001	-0.085 *	2.359	-0.001	0.001	-0.059	2.437
R^2					0.523				0.492				0.583	
Adjusted R^2					0.516				0.479				0.571	
F- Ratio					164,867***				81.689***				47.862***	
Df					10.000				19.000				21.000	

*p<0.05; **p<0.01; ***p<0.000

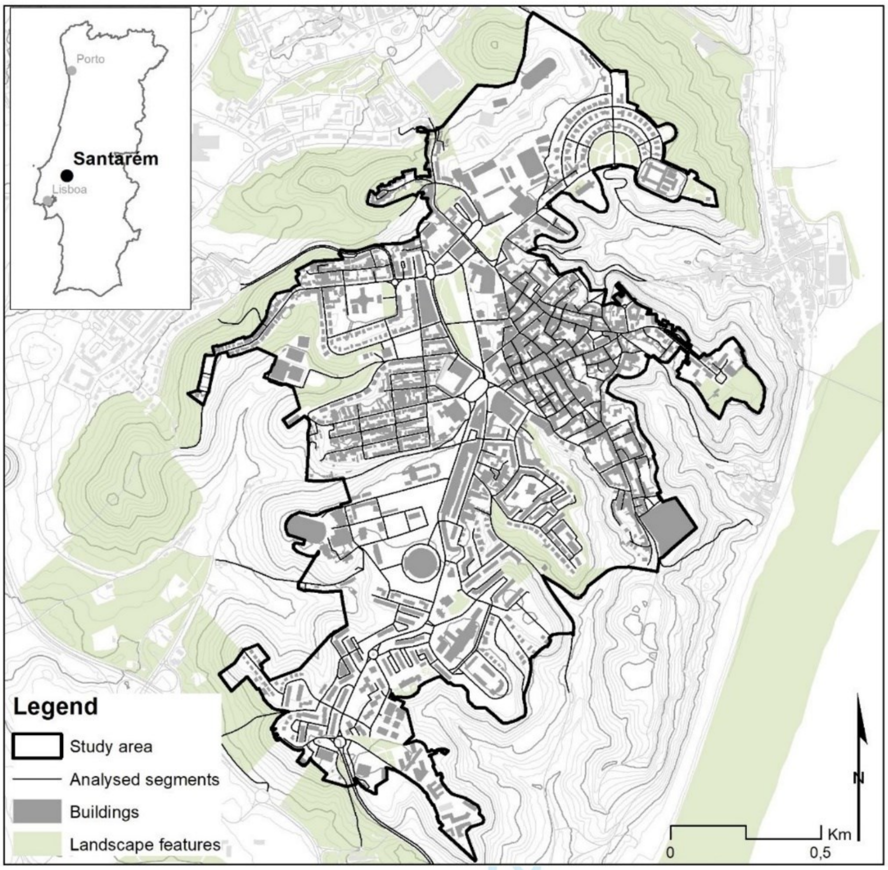
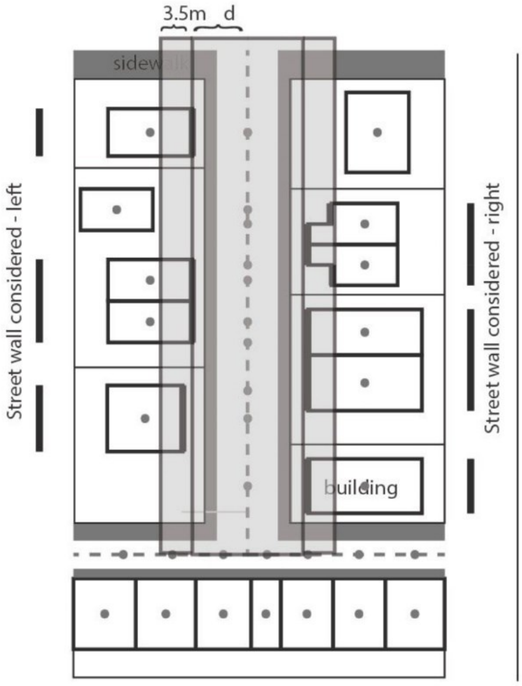


Figure 1: Santarém, Portugal.

Main Street 	Main street 
Modern residential street 	Residential street 
Commercial street 	Pedestrian street 

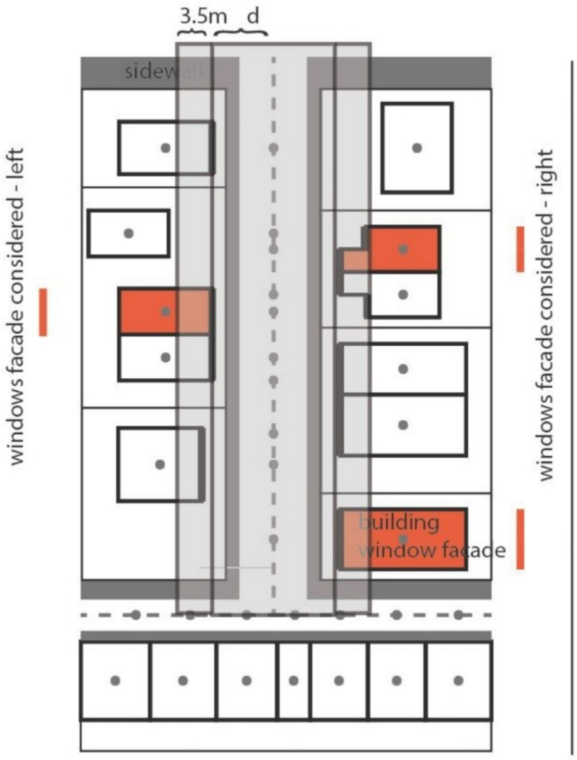
Figure 2: Street examples from the case study.



d is the buffer distance from the road centreline based on the distance to the closest building plus 3.5 meters

The street wall is defined by the length of streetfront inside the considered distance for each site, divided by two.

Figure 3: Proportion of street wall calculation (authors).



d is the buffer distance from the road centreline based on the distance to the closest building plus 3.5 meters.

The street wall is calculated as the length of the street front inside the buffer for each site, divided by two

$$Per\ Facades = \frac{\frac{Facades\ Left + Facades\ Right}{2}}{Street\ segment\ length} \times 100$$

Figure 4: Calculation of the proportion of building facades (authors).

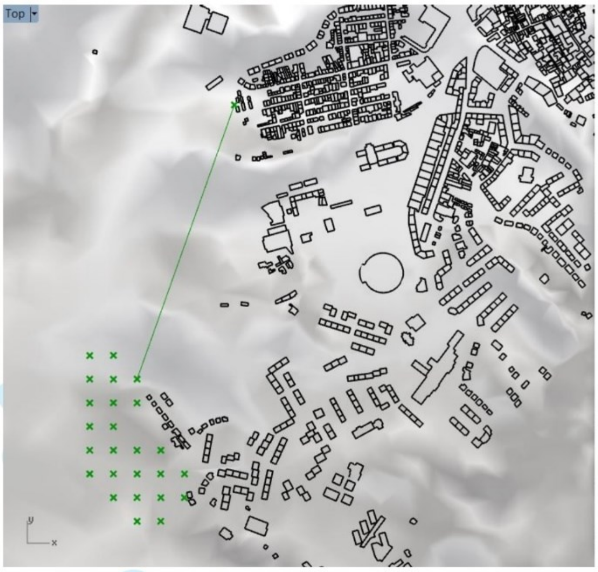


Figure 5: Model to calculate the visibility of major landscape features.

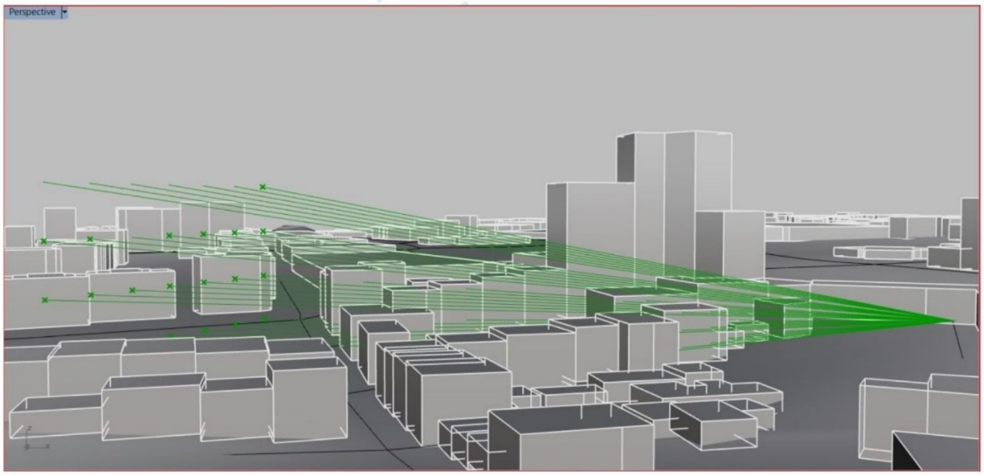


Figure 6: Model to calculate the proportion of visible sky.

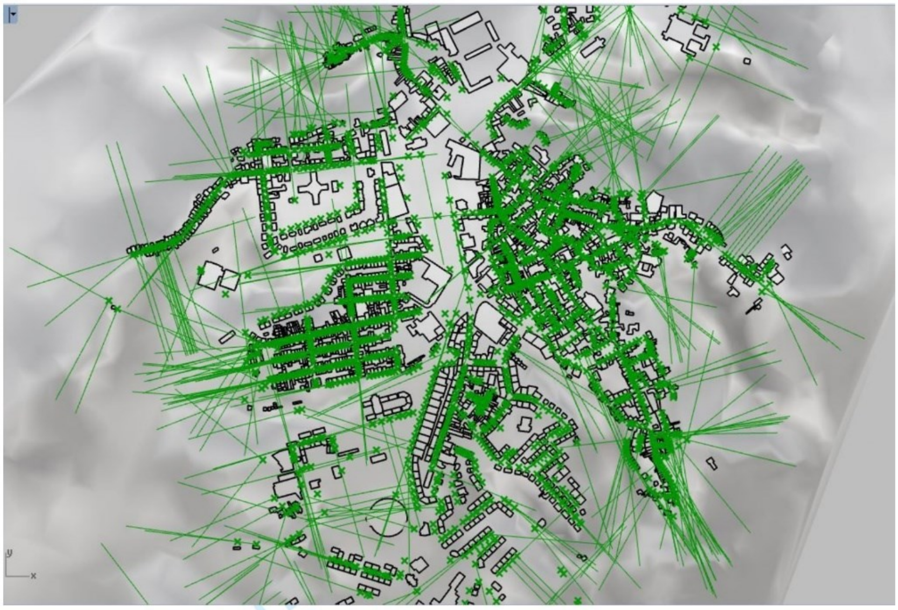
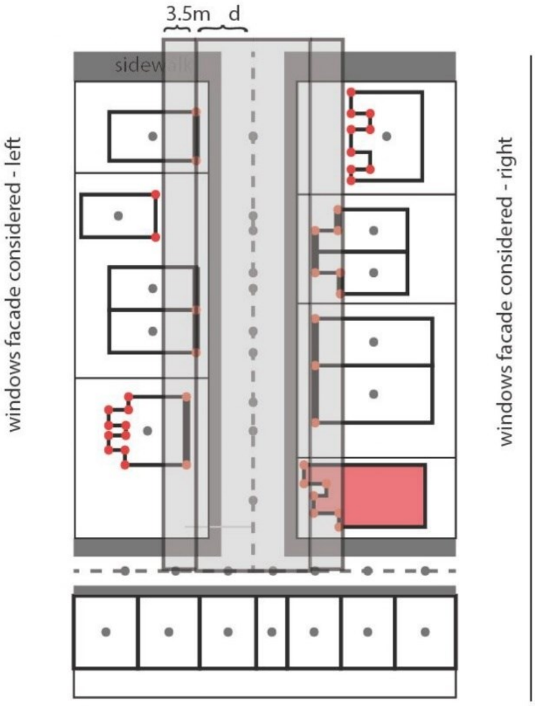


Figure 7: Number of long sightlines.



Buildings with more than six vertices count as buildings with a non-rectangular shape.

Buildings with a façade with more than six vertices, but outside the buffer or not on the street front are not counted.

In this example, only one building is considered to have a non-rectangular shape.

Figure 8: Method to identify non-rectangular buildings (authors).

Figure 1: Santarém, Portugal.

Figure 2: Street examples from the case study.

Figure 3: Proportion of street wall calculation (authors).

Figure 4: Calculation of the proportion of building facades (authors).

Figure 5: Model to calculate the visibility of major landscape features.

Figure 6: Model to calculate the proportion of visible sky.

Figure 7: Number of long sightlines.

Figure 8: Method to identify non-rectangular buildings (authors).

6 Discussão das principais conclusões

6.1 Resumo dos principais resultados

A Tabela 2 sistematiza as principais conclusões dos artigos da tese de doutoramento. As conclusões são discutidas ao longo deste capítulo.

Tabela 2 - Resumo das principais conclusões

Artigo científico	Principais resultados	Objetivos
I. A relação entre o walkability e a saúde na Área Metropolitana de Lisboa – a sua relação direta e indireta	Os vários modelos testados para explicar os internamentos hospitalares para várias doenças não comunicáveis mostraram que a hipertensão possui o modelo como melhor explicação, considerando as questões do ambiente construído. Quando exploradas as relações de moderação e de mediação das diferentes variáveis para explicar os internamentos por hipertensão, concluiu-se que o indicador de caminhabilidade influencia a qualidade do ar e o uso dos modos ativos. O uso dos modos ativos também se mostrou importante para a explicação dos internamentos por hipertensão. A importância do indicador de caminhabilidade para a explicação dos internamentos hospitalares é reforçado pelo seu contributo direto e indireto nas diferentes variáveis.	**O3** – Relação entre a caminhabilidade e a saúde.
II. The relationship between built environment and health in the Lisbon Metropolitan area – can walkability explain diabetes' hospital admissions?	O modelo de regressão linear múltipla para explicar as admissões hospitalares por diabetes confirma a importância do ambiente construído pelo seu papel mediador sobre as variáveis da qualidade do ar e o uso dos modos ativos. Os espaços verdes contribuem para melhorar a qualidade do ar influenciando, indiretamente, as admissões hospitalares por diabetes. O modelo sugere que a qualidade do ar e o uso dos modos ativos apresentam-se como variáveis de mediação para explicar as admissões hospitalares por diabetes. A densidade de	**O3** – Relação entre a caminhabilidade e a saúde.

	empregos é a variável mais importante para a explicação do uso dos modos ativos. No contexto da AML, os resultados sugerem que os espaços com melhor caminhabilidade são aqueles onde também existe pior qualidade do ar. Essa conclusão deve-se aos elevados níveis de correlação entre o índice de caminhabilidade e a pior qualidade do ar. Uma conclusão inesperada foi a reduzida importância do índice de privação para explicar as admissões hospitalares por diabetes. Este resultado levanta questões, por um lado, sobre a validade do uso deste indicador para descrever a condição socioeconómica e, por outro, sobre a avaliação da condição socioeconómica através de dados agregados aos limites administrativos para descrever os resultados individuais. No entanto, o indicador que considera as habitações sobrelotadas mostrou-se importante para explicar as admissões hospitalares por diabetes. Estes resultados sugerem a discussão sobre a validade dos indicadores socioeconómicos usados para avaliar a privação social.	
III. The relationship between the population's socio-economic status and walkability measures: the context of the Lisbon metropolitan area	O indicador do valor da propriedade é aquele que apresenta um padrão menos aleatório, com concentração de valores elevados no centro de Lisboa e na linha de Cascais. O centro da cidade de Lisboa é claramente diferente da restante AML, apresentando o melhor índice de caminhabilidade. Os resultados são semelhantes para as zonas a 15'' (minutos) do centro da cidade que apresentam os melhores índices de caminhabilidade. É também nestas zonas onde existe a maior relação entre as condições socioeconómicas e a caminhabilidade. No geral, não se conclui uma relação entre as características socioeconómicas e as condições de caminhabilidade na AML.	**O1** – Criação de indicador de caminhabilidade. **O2** – Testar e adaptar o indicador proposto ao contexto português.

	A maior correlação existe entre a caminhabilidade e a propriedade do solo. Por sua vez, existe uma relação entre o valor da propriedade e o acesso ao transporte público.	
IV. Is walkability equitably distributed across socio-economic groups? – A spatial analysis for Lisbon metropolitan area	O indicador socioeconómico apresenta um valor de correlação espacial baixo (Moran I=0.257, pseudo p-value =0.001). No entanto, os mapas de autocorreção espacial local (LISA) indicam zonas de concentração de grupos de baixa condição socioeconómica nos subúrbios a norte do concelho de Lisboa. As qualidades de caminhabilidade apresentam uma elevada correlação espacial, sendo o transporte público a variável com indicador de Moran I mais elevado (I = 0.769, pseudo p-value =0.001). Os mapas mostram uma clara distinção entre o centro da cidade de Lisboa e o resto da zona urbana da AML. Os resultados apresentam uma baixa correlação espacial com indicadores de Moran I relativamente baixos. A análise de correlação espacial bivariada entre as qualidades de caminhabilidade e as condições socioeconómicas sugerem *clusters* de zonas de elevada caminhabilidade, em particular, zonas com maior oferta de transporte público. Os resultados mostram a baixa correlação espacial entre as condições socioeconómicas e as qualidades de caminhabilidade. No entanto, é evidente a desigualdade na distribuição das qualidades da caminhabilidade, nomeadamente, a oferta do transporte público.	**O1** – Criação de indicador de caminhabilidade. **O2** – Testar e adaptar o indicador proposto ao contexto português.
V. The contribution of design dimension for utilitarian and leisure walking – the relative influence of connectivity measures and streetscape features	Os resultados mostram que os modelos que utilizam os indicadores de conetividade têm um R^2 ajustado ligeiramente mais elevado do que os modelos que utilizam os indicadores das características do desenho da rua para explicar as deslocações a pé utilitárias e as deslocações a pé em geral.	**O1** – Criação de indicador de caminhabilidade. **O2** – Testar e adaptar o indicador proposto ao

	Os modelos que combinam os indicadores de conetividade e do desenho da rua têm um R^2 ajustado mais elevado para os diferentes motivos de viagem. No entanto, os diferentes indicadores têm uma importância diferente tendo em conta o motivo das viagens. Os resultados identificam diferenças na influência dos indicadores para explicar as viagens por lazer e utilitárias. Nas viagens por lazer, a influência dos indicadores densidade habitacional e densidade dos serviços é menor. As medidas de acessibilidade tornam-se também menos importantes. A densidade de serviços e de comércio também é menos importante. O acesso aos transportes públicos é menos importante para as viagens de lazer em comparação com as utilitárias. O modelo com os indicadores de desenho da rua é o que apresenta menor poder explicativo em comparação com as medidas de conetividade e com os indicadores combinados. As medidas de conetividade têm maior poder explicativo do que os modelos que usam os indicadores do desenho da rua. No entanto, a avaliação conjunta da conetividade e dos indicadores do desenho da rua apresentam melhor desempenho. A acessibilidade pedonal é importante, especialmente para viagens utilitárias. Os resultados confirmam a importância da forma urbana avaliada por medidas de conetividade para explicar viagens com diferentes motivos. No entanto, a introdução de características à escala da rua pode ajudar a explicar melhor as deslocações a pé.	contexto português.

Os vários artigos e o seu encadeamento cronológico e teórico resultam de uma descoberta natural da complexidade dos temas em análise. O tema da caminhabilidade surgiu como consequência da minha anterior experiência profissional dedicada à avaliação do espaço público na perspetiva da acessibilidade universal. Nesta altura, o contacto com o termo caminhabilidade, ou *walkability*, foi uma consequência da investigação profissional para avaliar as condições de caminhabilidade no seu todo, mas, em particular, para pessoas com mobilidade reduzida. No entanto, e para além dos vários benefícios associados aos espaços mais caminháveis, foi a relação entre caminhabilidade e atividade física que justificou o interesse inicial. O primeiro contacto com o tema foi através de estudos, como os divulgados no site Walkscore (https://www.walkscore.com/), ou os desenvolvidos pelo IPEN (https://www.ipenproject.org/index.html), que justificaram o interesse em estudar e aplicar essas metodologias à cidade de Lisboa. De facto, o contexto de estudo inicial era apenas a cidade de Lisboa, porém, tendo em conta a importância dos transportes públicos para os níveis de atividade física (Buehler et al., 2018; Saelens & Handy, 2008) e a forma como a cidade de Lisboa recebe indivíduos de toda a AML justificaram alargar a investigação à AML.

6.2 Discussão dos resultados

O primeiro artigo está muito relacionado com esta visão da saúde na perspetiva da doença e de como a cidade a pode evitar, neste caso, promovendo a atividade física através dos modos ativos e reduzindo o uso do automóvel com impacto na qualidade no ar. Este é o artigo mais próximo à literatura que serviu de base à elaboração da proposta de doutoramento, contendo o que muitas das revisões da literatura sobre a relação da cidade e a saúde sugerem em termos de metodologias e indicadores (Arcaya et al., 2016; Brownson et al., 2009; Papas et al., 2007). No artigo é proposto, e testado para o contexto português, um indicador de caminhabilidade semelhante aos mais utilizados na literatura. Por outro lado, são avaliados outros aspetos como a oferta de transporte público e os espaços verdes.

O artigo assenta na premissa de que o ambiente construído influencia a atividade física, neste caso, o uso dos modos ativos, e que estes influenciam a saúde, ou, neste caso, a doença. Os resultados confirmam, para o contexto da AML, o que a literatura sugere para contextos mais distantes como os EUA, o Canadá ou a Austrália (Arcaya et al., 2016; Mueller et al., 2015): que o ambiente construído influencia a saúde, neste caso, a diabetes do tipo 2, que está intimamente ligada ao estilo de vida (Auchincloss, 2009; Sundquist, Eriksson, Mezuk, & Ohlsson, 2015). No entanto, mais que confirmar essa relação para o contexto português, sugere-se um modelo onde qualidade do ar e uso dos modos ativos mediam o contributo das restantes características do ambiente construído e socioeconómicas para explicar a diabetes. Este tipo de modelos que consideram relações mais complexas são sugeridos pela literatura como os mais eficientes para avaliar a relação entre o ambiente construído e da saúde, porém, devido à sua complexidade, nem sempre são explorados e aplicados (Barton, 2017; Sallis et al., 2006).

O uso de modelos ecológicos conduziu a uma análise mais profunda sobre a questão da saúde e de como esse conceito é complexo tendo em conta a sociedade moderna. Segundo a OMS, a saúde não é apenas a ausência da doença, *mas um sentimento de completo bem-estar* (World Health Organization, 1986), ou seja, é possível ter diabetes ou hipertensão e ainda assim ser perfeitamente feliz ou ter um ótimo bem-estar. De facto, a sociedade moderna cada vez mais complexa e exigente traz outro tipo de riscos para a saúde, em especial, para a saúde mental (Liu et al., 2019; Loureiro et al., 2019; Sui, Ettema, & Helbich, 2022). O indivíduo é cada vez mais complexo e a sua concretização pessoal, profissional e comunitária é aquilo que lhe traz bem-estar. Desta forma, surgem os conceitos de bem-estar, bem-estar subjetivo, ou felicidade. Estes conceitos estão intimamente ligados à saúde mental (Krekel, Kolbe, & Wüstemann, 2016; Ma, Kent, & Mulley, 2018).

A saúde e a saúde mental, bem como aquilo que o indivíduo alcança na vida, estão relacionados com a sua condição socioeconómica (Carstairs, 1995; Jiao et al., 2016). Foi sobre essa premissa e como resultado de análises exploratórias que sugeriam uma relação entre as condições socioeconómicas e as qualidades do ambiente construído, que os dois artigos seguintes foram elaborados. Na literatura sobre a caminhabilidade é muito frequente avaliar a sua relação com as condições socioeconómicas (Adkins et al., 2017; Gullón et al., 2017; King & Clarke, 2015), principalmente em contextos norte-americanos, onde a segregação social é mais forte. No entanto, em alguns estudos na Europa essa relação não se havia confirmado (Gullón et al., 2017). No contexto da AML pouco se sabia sobre a distribuição das qualidades de caminhabilidade e sobre a população dos diferente extratos socioeconómicos. A abordagem do capítulo do livro (artigo III) sobre este tema foi uma análise estatística de correlações entre os vários indicadores, considerando a distância ao centro da cidade. No capítulo conclui-se que a relação entre as condições socioeconómicas e as qualidades de caminhabilidade é fraca. O indicador de correlação mais elevado entre as condições socioeconómicas e a caminhabilidade acontece na zona mais central da cidade de Lisboa. De facto, os resultados mostram que os melhores índices de caminhabilidade estão na zona mais central da cidade e pioram à medida que nos afastamos do centro. Contudo, a percentagem de população com piores condições de caminhabilidade na AML é bastante baixa (apenas 2 % da população vive a mais de 45 minutos de carro do centro de Lisboa). Embora não exista uma forte correlação entre as condições de caminhabilidade e as condições socioeconómicas, existe uma grande disparidade na distribuição dos índices de caminhabilidade.

No IV artigo a temática é semelhante, mas é incluída e desenvolvida a componente espacial para avaliar a correlação entre as condições socioeconómicas e as qualidades do ambiente construído. Os resultados mostram que, em termos globais, não existe correlação espacial, isto é, não existe uma clara distinção entre norte, sul, ou uma bipolarização entre zonas. Neste caso, existe população mais desfavorecida em zonas de boas e más condições de caminhabilidade e o mesmo acontece para a população menos desfavorecida. Não obstante, analisando em maior detalhe os mapas de correlação espacial local (LISA), são visíveis *clusters* de zonas, neste caso, subsecções estatísticas, onde existe uma concentração de baixas condições socioeconómicas e de bons índices de caminhabilidade, principalmente junto à linha ferroviária. Uma das conclusões mais importantes deste artigo é que, embora não exista discriminação entre pobres e ricos na sua distribuição na AML, existe uma grande desigualdade na distribuição das qualidades do ambiente construído, principalmente em relação à oferta de transporte público. A desigualdade do transporte público afeta de forma mais significativa os estratos socioeconómicos mais desfavorecidos, já que as alternativas de mobilidade são mais reduzidas (Currie & Delbosc, 2010). A desigualdade da oferta de espaços caminháveis contribui também para a perceção que cada um tem sobre o local onde vive e essa perceção tem um impacto sobre a forma como o indivíduo se vê e sobre aquilo que alcançou tendo em conta onde mora (Jiao et al., 2016; Lockwood, Coffee, Rossini, Niyonsenga, & McGreal, 2018). A perceção do indivíduo sobre as qualidades da zona envolvente influenciam também as suas deslocações a pé (Kerr et al., 2016).

No artigo V é avaliada a contribuição relativa entre as características do desenho da rua e os indicadores de conectividade da rede, que definem a forma da cidade para as deslocações pedonais. Os resultados mostram que a forma urbana, avaliada pelos indicadores de conectividade, é mais importante do que as características do desenho da rua para explicar as deslocações utilitárias e de lazer. Contudo, ambas as dimensões são importantes para explicar essas deslocações e devem ser avaliadas, uma vez que o modelo que contempla ambos os indicadores apresenta o melhor poder explicativo. O artigo contribui com metodologias para avaliar indicadores de escala de maior detalhe, tirando partido das ferramentas SIG, e sugere a introdução destes indicadores nos índices de caminhabilidade. O artigo foca-se nas questões das deslocações pedonais e em como estas são influenciadas pelas diferentes dimensões da cidade, desde a escala macro, da estrutura da cidade, até uma escala mais micro, com o desenho da rua. O artigo explora o contributo destes dois níveis para as deslocações a pé, utilitárias e de lazer. Neste artigo, a escala de análise é feita ao nível do edifício, avaliando-se as características da sua área envolvente, e considerando nessa análise diferentes indicadores para descrever as condições que influenciam as deslocações pedonais. Os indicadores de conectividade são avaliados para essa área de influência, descrevendo a forma urbana por oposição aos indicadores de maior detalhe ao nível das características da rua. Estes últimos são importantes para a perceção do indivíduo, pois condicionam as deslocações a pé, mas são também importantes para a perceção individual acerca da saúde e bem-estar (Jiao et al., 2016; Kyttä et al., 2016; Stefansdottir, 2018).

Os cinco artigos avaliam o contributo de características à escala metropolitana que influenciam os resultados em saúde, mas também exploraram o contributo da escala da rua para influenciar esses resultados. A distribuição socioeconómica da população é avaliada à escala metropolitana. O artigo de Santarém avalia o contributo do ambiente construído à escala da área de influência da residência e as características da rua para afetar as deslocações a pé. Os modelos ecológicos sugerem que os resultados em saúde são influenciados por várias escalas de contexto do indivíduo, do mais próximo, como a casa e o bairro, até à cidade e o país onde se insere (Barton & Grant, 2006). Os cinco artigos exploraram o contributo das diferentes escalas do ambiente urbano para influenciar a saúde do indivíduo, não só pelo risco de doença, mas também pela promoção de hábitos de vida mais saudável, nomeadamente, contemplando a mobilidade ativa. Finalmente, consideram características de detalhe das qualidades da rua, que condicionam a perceção do individuo face a esses locais. Essa perceção dita a atratividade de determinado local, mas também o sentimento e o bem-estar face ao local onde se vive.

6.3 O ambiente construído e a saúde mental

A investigação deste doutoramento explorou a relação entre as diferentes escalas de contexto do ambiente construído para explicar a incidência da hipertensão, da diabetes, e da saúde mental para o contexto da AML. No entanto, a exigente modelação estatística para a avaliação desta multi-escala que envolve diversas varáveis latentes, não permitiu resultados robustos que comprovassem as teorias propostas referentes ao impacto na saúde mental. Não obstante, os modelos testados e explorados permitiram sugerir teorias e abordagens para a avaliação das diferentes escalas, de modo a explicar a saúde mental na AML. A Figura 9 ilustra o modelo teórico proposto e testado para explicar o contributo das diferentes escalas de contexto urbano para a incidência de diabetes e de hipertensão e para a saúde mental.

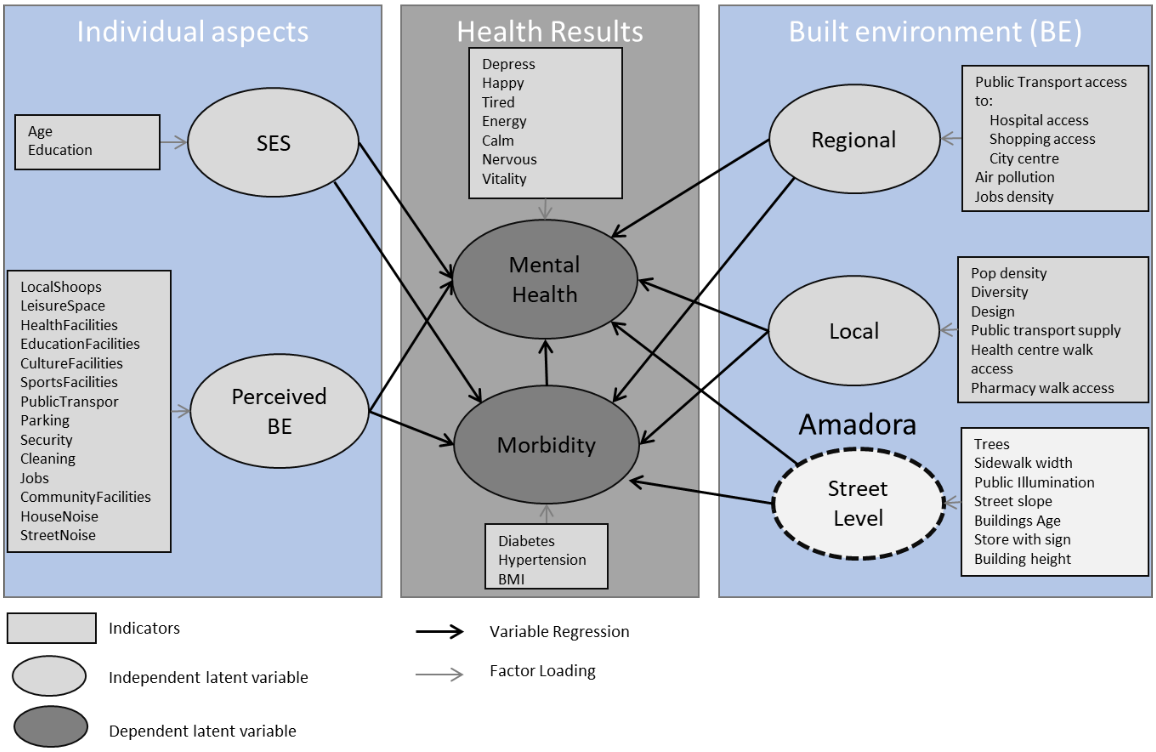


Figura 9 - Modelo proposto e testado para a relação entre escalas de ambiente construído e a saúde mental.

Os modelos propostos e testados, que partem do modelo teórico proposto, usam várias escalas de contexto para explicar os resultados em saúde, mais concretamente, a saúde mental e a presença de hipertensão e diabetes. A investigação avaliou as características do ambiente construído ao nível regional e local para quatro concelhos da AML - Lisboa, Oeiras e Mafra, incluindo a escala da rua para o concelho da Amadora. Os resultados sugerem a importância da perceção das qualidades do ambiente construído para influenciar a saúde mental (Kan, Kwan, Ng, & Tieben, 2022; Oviedo, Sabogal, Villamizar Duarte, & Chong, 2022). Os resultados indicam que ambas as escalas, regional e local, apresentam um contributo semelhante para a saúde mental. Neste caso, a saúde mental testada corresponde a uma variável latente que resulta da resposta a várias questões sobre a perceção individual da saúde mental.

Nas análises testadas, os índices desenvolvidos e usados nas fases anteriores, bem como os seus componentes, como o valor da propriedade ou a habitações sobrelotadas, não se mostram importantes para explicar a saúde ou o bem-estar. O processo de modelação para a obtenção dos modelos propostos levou à eliminação de várias variáveis que, teoricamente, seriam importantes. No entanto, os modelos finais sugerem a confirmação de premissas naturais sobre a relação das questões biológicas com as questões da saúde e bem-estar, mas também o reforço da importância das questões da perceção do ambiente construído para a melhoria da saúde e do bem-estar. Estes resultados estão alinhados com investigação anterior para o concelho da Amadora que indicam a perceção do ambiente construído, particularmente a relacionada com o sentimento de insegurança, cria um fator patogénico de mal-estar o que resulta uma menor fruição das oportunidades providenciadas pela cidade (Santana & Roque, 2007). Os modelos criados, ao relacionarem os vários níveis de contexto de ambiente construído para a morbilidade e a saúde mental do indivíduo, confirmam a importância desses contextos para explicar a saúde.

Ao avaliar os vários níveis de contexto, os resultados indicam que a escala do bairro, descrita como contexto local, é a mais significativa para explicar a relação do ambiente contruído com a morbilidade e com a saúde mental. Essa conclusão é reforçada pela importância da questão da perceção individual do ambiente construído, avaliada para o contexto do bairro da morada do indivíduo. A perceção da escala do bairro define também aquilo que o indivíduo identifica com o seu bairro, a sua relação de vizinhança e os contactos sociais com a comunidade. Estudo anteriores, mostram que na Amadora, existem concentrações espaciais de clusters de áreas potencialmente carenciadas o que pode inflacionar o impacto desse contexto para a saúde individual (Santana, Nogueira, Costa, & Santos, 2007).

No exercício de modelação estatística foram testados modelos de equações estruturais, uma técnica estatística com um caráter confirmatório, que testa a validade de um modelo teórico (Kline, 2011; Marôco, 2010). Os modelos propostos e testados são construídos com base na literatura sobre a relação do ambiente construído e a saúde mental (Currie & Delbosc, 2010; Kroesen & van Wee, 2022; Oviedo et al., 2022; Peng, Peng, Feng, Zhong, & Wang, 2021; Vale & Pereira, 2016).

O modelo de equações estruturais proposto para os quatro concelhos (Amadora, Oeiras, Mafra e Lisboa) revela uma relação pouco significativa entre as características do ambiente construído para explicar a morbilidade e a saúde mental dos indivíduos. A componente das características individuais é a mais importante para explicar as variáveis dependentes. Destas componentes individuais fazem parte as características individuais biológicas e socioeconómicas, nomeadamente, a idade e a educação. Fazem ainda parte as questões emocionais relacionadas com a perceção individual do ambiente construído do bairro. De facto, esta perceção das características do ambiente construído é a que apresenta a relação mais forte para explicar a morbilidade e a saúde mental. Nos três níveis de contexto de ambiente construído considerados, o regional, o local e o da rua, o local é aquele que apresenta a relação mais forte. No entanto, esta relação, em conjunto com o impacto da perceção do ambiente construído, reforçam a importância das qualidades urbanas para a promoção de cidades mais saudáveis.

6.4 Discussão dos resultados e avaliação dos objetivos.

Os cinco artigos que resultam desta investigação cobrem as diferentes escalas de ambiente construído que podem influenciar a saúde e o comportamento do indivíduo, utilizando indicadores de maior e menor detalhe. Os resultados dos artigos I e II confirmam a importância do desenvolvimento urbano suportado no transporte público como forma de reduzir a incidência de doenças não comunicáveis e aumentar os níveis de atividade física (Saelens, Moudon, Kang, Hurvitz, & Zhou, 2014; She, King, & Jacobson, 2019). O desenvolvimento urbano que promove melhor níveis de saúde deverá contemplar uma oferta de espaços verdes de dimensão e de qualidade (Q. Wang & Lan, 2019). O papel dos espaços verdes é fundamental pelo seu contributo para a melhoria da qualidade do ar através da captação de carbono (Jaafari, Shabani, Moeinaddini, Danehkar, & Sakieh, 2020; Pauleit, Zölch, Hansen, Randrup, & Konijnendijk van den Bosch, 2017), mas também pelo seu papel de suporte à atividade física de lazer (Sarkar et al., 2015; Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013; Q. Wang & Lan, 2019). Os resultados ao nível da área metropolitana destacam que o desenvolvimento urbano da área metropolitana falha na distribuição equitativa dos principais equipamentos de saúde, e também na oferta de modos de transporte sustentável, nomeadamente, o transporte público.

Os artigos III e IV reforçam a desigualdade espacial das qualidades do ambiente construído na AML, com a concentração dos melhores indicadores de caminhabilidade no centro da cidade de Lisboa, em comparação com a restante área metropolitana. A desigualdade espacial mantém-se em relação aos equipamentos de saúde, onde Lisboa concentra grande parte dos equipamentos, e também existe esta desigualdade no que respeita à melhor oferta de transporte público e na proximidade aos principais pontos de lazer, como o Parque de Monsanto e a frente ribeirinha. Os resultados reforçam a importância da escala metropolitana para a satisfação das necessidades individuais, desde logo, pelo acesso aos serviços de saúde, mas, principalmente, pelo acesso às diferentes atividades do dia-a-dia. O acesso ao emprego tem um peso muito significativo no centro de Lisboa, que concentra muitas das principais atividades, tornando a cidade de Lisboa o principal destino dos habitantes da área metropolitana (INE, 2018; Santos, 2017). A grande desigualdade da oferta de transporte público resulta numa grande percentagem do uso do automóvel (Santos, 2017). A escala metropolitana é fundamental para os movimentos pendulares, tendo os artigos I e II mostrado como as opções de mobilidade são importantes paras as doenças não comunicáveis. No entanto, a área envolvente ao local onde residimos pode ajudar a minimizar o impacto da localização dessa residência a nível metropolitano e a nível regional.

O artigo V e o ensaio à questão da saúde mental exploraram o contributo do contexto mais próximo do indivíduo para os resultados em saúde. O artigo V é particularmente focado no aspeto da atividade física traduzido pelas deslocações pedonais. Neste artigo, é avaliado o contexto local da zona de residência do indivíduo, usado em grande parte da literatura sobre o impacto do ambiente construído na saúde (Mavoa, Bagheri, Koohsari, & Kaczynski, 2019; Ribeiro, 2018; Roux, 2001). Os resultados mostram que a forma urbana, composta pelos seus quarteirões e rede viária, é aquela que mais condiciona as deslocações pedonais. Estes resultados reforçam as conclusões dos artigos anteriores no que concerne à importância das questões da forma urbana para explicar a mobilidade dos indivíduos. Contudo, o mesmo artigo aponta para a importância das qualidades da rua para explicar as deslocações a pé por lazer. As deslocações por lazer são mais sensíveis às qualidades urbanas. A inexistência dessa qualidades urbanas resulta no redução ou mesmo ausência das deslocações por lazer (Steinmetz-Wood, El-Geneidy, & Ross, 2020). As qualidades urbanas têm particular impacto da perceção do indivíduo, influenciando não só as deslocações pedonais, mas também outros aspetos relacionados com segurança. A perceções individuais sobre o ambiente construído condicionam também o bem-estar que determinado local transmite (Jun & Hur, 2015; Kent et al., 2017). Os resultados sugeridos pela investigação sobre o contributo das diferentes escalas para a saúde mental sugerem a importância da perceção do ambiente construído nos resultados em saúde, em particular, na saúde mental. A perceção do ambiente construído e as características socioeconómicas apresentam-se como as dimensões mais importantes para explicar a saúde mental e a variável latente medida pela incidência de diabetes e de hipertensão. Contudo, a avaliação das características do ambiente construído, medidas ao nível do contexto da rua, não se mostraram significativas para a explicação dessas mesmas variáveis. Por outro lado, o contexto local definido pela área envolvente de 500 metros em torno da residência foi o que se mostrou mais importante para explicar as variáveis dependentes. Este resultado confirma a importância da área envolvente do indivíduo, o seu bairro, como o mais importante para os resultados em saúde, justificando a sua utilização em muita da literatura sobre o impacto do ambiente construído na saúde (Mavoa et al., 2019; Ribeiro, 2018; Roux, 2001). Contudo, a importância da perceção, bem como dos indicadores locais e regionais identificados nos vários modelos, sugerem a necessidade de uma visão ecológica da contribuição das diferentes escalas de contexto para alterar comportamentos e melhorar o estado de saúde da população (Sallis et al., 2006). De facto, só uma alteração articulada nas diferentes dimensões e contextos poderá ter sucesso na promoção de estilos de vida mais ativos e saudáveis.

6.4.1 Objetivo 1 – criação de um indicador de caminhabilidade

O primeiro objetivo consistia na criação de um indicador de caminhabilidade para avaliar as características do ambiente construído que influenciam a saúde da população e que servisse como ferramenta para arquitetos e urbanistas no planeamento da cidade. Este objetivo pretendia responder à questão de quais são as características de um ambiente caminhável que contribuem para a saúde da população. O desenvolvimento da investigação do doutoramento revelou que não eram apenas questões de caminhabilidade que influenciam a saúde da população. As características de caminhabilidade são fundamentais como infraestrutura de suporte a uma mobilidade mais ativa e saudável. No entanto, a estrutura metropolitana, que inclui a distribuição de equipamento de saúde, espaços verdes e mobilidade, é crucial como princípio e fim de uma mobilidade pedonal. A investigação permitiu concluir que a questão da caminhabilidade é importante e útil para alterar hábitos e estilos de vida, mas apenas considerando condições metropolitanas é possível planear cidades mais ativas e saudáveis. O objetivo da criação deste indicador era servir como ferramenta a arquitetos e urbanistas. Porém, desde logo por incluir profissionais distintos, arquitetos e urbanistas, percebe-se que um indicador não seria igualmente útil para as diferentes escalas do ambiente construído. Deste modo, e pela inclusão de diferentes indicadores não todos de carácter urbano, como a qualidade do ar, chegou-se à conclusão de que um indicador único não seria a ferramenta mais útil quando o objetivo é intervir no território. O indicador é útil como primeira análise e síntese de uma situação atual, mas para arquitetos e urbanistas as diferentes dimensões que constituem esse indicador são mais úteis para a definição de estratégias e de medidas de intervenção. De qualquer modo, ao longo da investigação foram ensaiados e testados diferentes indicadores de caminhabilidade que, para além dos aspetos da caminhabilidade, incluíram questões como o acesso a espaços verdes e a oferta de transportes públicos. Estes indicadores permitiram uma avaliação do contexto da caminhabilidade para a cidade de Lisboa e para a AML.

6.4.2 Objetivo 2 – testar e adaptar o indicador proposto ao contexto português

O segundo objetivo da tese consistia em testar e adaptar os indicadores de caminhabilidade existentes ao contexto português, em particular, à diversidade territorial e socioeconómica da AML. O objetivo pretendia responder à questão de como as condições do contexto português, em particular, da AML, poderiam influenciar na formulação de um indicador de caminhabilidade para explicar os resultados em saúde.

Os resultados da investigação confirmaram a complexidade territorial da AML, considerando a sua distribuição socioeconómica e as características do ambiente construído. Ao contrário do que existe em outros contextos, onde é grande o desenvolvimento dos indicadores de caminhabilidade, não se verificou uma correlação entre as condições socioeconómicas e as qualidades urbanas. A distribuição territorial da população e dos principais equipamentos de saúde, lazer, ou centros de emprego mostraram a dificuldade em criar um indicador que avaliasse essas características às várias escalas. Por outro lado, os resultados demonstram a importância da atribuição de pesos diferenciados a diferentes componentes dos indicadores de ambiente construído para explicar os resultados em saúde. A investigação sugere, mais do que um indicador composto, várias componentes a considerar para avaliar o impacto em saúde, revelando relações complexas de mediação e moderação entre as variáveis. A criação de um indicador composto não permite considerar as relações de mediação e de moderação entre as variáveis que formam esse indicador, que a literatura aponta como sendo importante para a complexa relação entre o ambiente construído e a saúde. A inclusão de diferentes escalas do ambiente construído para explicar a saúde propõe diferentes indicadores, considerados a diferentes escalas do ambiente construído e com diferentes impactos no complexo estado de saúde e perceção do mesmo.

6.4.3 Objetivo 3 – relação entre a caminhabilidade e a saúde

O terceiro e último objetivo da tese pretendia avaliar a relação entre o conceito de caminhabilidade e os resultados em saúde, procurando responder à questão de como as características de um ambiente caminhável se relacionam com os aspetos de saúde e bem-estar da população. Neste âmbito, a investigação foi além do objetivo proposto, extravasando a avaliação do ambiente construído sobre a vertente da caminhabilidade, e apresentando uma visão mais holística das várias dimensões do ambiente construído. Desta avaliação, a investigação considerou não só os aspetos de caminhabilidade, mas também questões de acessibilidade a equipamentos de saúde de diferentes valências, e ainda aspetos relacionados com a qualidade do ar. A investigação mostrou a relação do ambiente construído com doenças não comunicáveis, tais como a hipertensão ou a diabetes, para o contexto da AML. Por outro lado, sugeriu a importância das qualidades urbanas para as deslocações pedonais, tanto utilitárias como de lazer, indicando o seu contributo para um aumento da atividade física por via destas deslocações pedonais. Finalmente, ensaiou o contributo das diferentes escalas urbanas para a explicação da saúde mental, que, embora não tendo resultados definitivos, sugere interessantes resultados sobre o contributo da perceção do indivíduo sobre o contexto urbano para explicar a sua saúde mental.

6.5 Limitações

Os resultados obtidos nos vários artigos são um contributo importante para a área do conhecimento do urbanismo e também da saúde, embora não estejam isentas de limitações. Desde logo, a diversidade de variáveis utilizadas, embora permitindo uma cobertura abrangente de realidade analisada, são provenientes de várias fontes com diferentes períodos de recolha. Na verdade, as questões do ambiente construído não sofrem alterações significativas, mas é importante apontar este aspeto. Outra limitação prende-se com os aspetos medidos para o indivíduo através do inquérito, que, sendo reportados pelo próprio indivíduo, podem não corresponder totalmente à realidade. Por fim, e tendo em conta que um dos objetivos do doutoramento era a criação de um indicador de caminhabilidade que traduzisse o impacto da saúde da população, o mesmo não se concretizou. A criação deste indicador foi testada em dois dos artigos, no entanto, nos restantes artigos, em resultado do processo de revisão para publicação, esse indicador acabou por ser eliminado por sugestão dos revisores. Durante a investigação, esse objetivo esteve sempre presente, tendo inclusivamente resultado num artigo em coautoria, onde foi desenvolvida uma ferramenta SIG para avaliação de um indicador de caminhabilidade para o contexto europeu (Fina et al., 2022).

Contudo, e tendo em conta a complexidade dos resultados obtidos, consideramos que um indicador composto não será a melhor ferramenta para o arquiteto poder intervir no território. O indicador de caminhabilidade é útil para uma primeira abordagem à realidade e permite comparar territórios, mas apenas os indicadores do ambiente construído, à semelhança de parâmetros urbanísticos, permitirão intervir no território nos aspetos concretos que podem influenciar a saúde.

6.6 Trabalhos futuros

O processo de leitura e análise da literatura sobre a temática levantou várias questões importantes e interessantes. Desde logo, a questão da alimentação e de como a oferta de alimentação saudável, ou falta dela, é fundamental para os níveis de obesidade (Stahl, Wismar, Ollila, Lahtinen, & Leppo, 2006). Por outro lado, a questão da avaliação do contributo ao nível do edifício para a saúde e bem-estar. A casa é a camada de contexto mais próxima do indivíduo e a qualidade da sua construção é fundamental para a saúde (Sarkar, Webster, & Gallacher, 2016), não só para o controlo das condições adversas do exterior, como o calor e o frio que são a causa de morte em muitos casos (Almendra, Santana, & Vasconcelos, 2017), mas também para o aspeto estético que contribui para a perceção individual sobre o seu local de residência com impacto no bem-estar.

A metodologias usadas da tese são principalmente quantitativas, tirando partido de diferentes abordagens estatísticas. Não obstante, tendo em conta a complexidade das perceções relacionadas com o ambiente construído, seria útil a exploração de abordagens qualitativas de análises mais profundas a essas perceções por grupos de indivíduos, recorrendo a técnicas como entrevistas ou percursos acompanhados. A utilização deste tipo de abordagens pode ser útil para a cocriação de projetos de intervenção do território que criem ambientes urbanos onde o sentimento de pertença dos seus habitantes é maior, contribuindo, assim, para ambientes mais saudáveis.

Finalmente, a nova realidade trazida pela pandemia do Covid 19 trouxe toda uma nova perspetiva da saúde e que levaria a uma abordagem completamente diferente sobre a avaliação do ambiente construído sobre a saúde. O processo de investigação exigiu escolhas sobre o foco das análises. Contudo, os temas mencionados poderão ser linhas de investigação futuras muito pertinentes que poderão tirar partido das conclusões da presente tese.

7 Conclusões

A presente tese de doutoramento contribui para o desenvolvimento do conhecimento numa área de charneira entre a saúde e o urbanismo. A tese coloca Portugal e a Área Metropolitana nos territórios que analisaram a relação entre o ambiente construído e a caminhabilidade. Por outro lado, avança na dimensão do contributo das características do ambiente construído para uma visão mais abrangente do que é a saúde. Num primeiro momento, apresenta os resultados para as doenças não comunicáveis, mais concretamente, a diabetes. Num segundo momento, avalia os contributos das questões socioeconómicas para a distribuição da população na cidade, que tem impactos na saúde. Por fim, confirma a relação complexa entre as variáveis do ambiente construído e a perceção para a saúde da população, sugerindo modelos que incluem uma relação de mediação entre as variáveis em estudo. Destes vários momentos considera-se importante destacar as seguintes conclusões:

- Avaliando admissões hospitalares para várias doenças não-comunicáveis, a hipertensão e a diabetes foram as doenças mais relacionadas com as características do ambiente construído. No caso da diabetes, ficou clara a importância da caminhabilidade e dos espaços verdes para mediar as variáveis da qualidade do ar e o uso dos modos ativos.
- Conclui-se que não existe uma relação espacial entre a condição socioeconómica e as qualidades do ambiente construído, existindo vários estratos socioeconómicos em zonas de diferentes qualidades de caminhabilidade. No entanto, ficou clara a grande desigualdade na distribuição das qualidades de caminhabilidade, em particular, a oferta de transporte público.
- A diferença entre o centro da cidade de Lisboa, em termos de caminhabilidade, é substancialmente desigual comparativamente à restante área metropolitana.
- No caso da investigação do contexto de Santarém, conclui-se que a forma urbana medida através da conectividade da rede apresenta maior importância na explicação das deslocações a pé do que nas questões do desenho da rua.
- A saúde mental é uma dimensão complexa de medir e os modelos propostos não apresentam um poder explicativo muito relevante. No entanto, confirma-se a importância da perceção do ambiente construído para esse bem-estar.
- As perceções do ambiente construído foram aquelas que se mostraram mais importantes para explicar a saúde e o bem-estar, sugerindo vantagens para a melhoria da saúde e do bem-estar da população.

Os resultados ilustram a complexidade das duas áreas do conhecimento e a sua interligação. A título de exemplo, a questão da complexidade da saúde é influenciada não só por questões biológicas, mas também sentimentais. Por outro lado, a questão da complexidade da cidade com os seus diferentes contextos e escalas que a formam e condicionam a vida dos seus habitantes. Por fim, a relação entre ambas as complexidades para explicar a saúde individual e da população. Os resultados, à semelhança do que sugere a literatura, indicam que só uma intervenção integrada nas diferentes escalas urbanas e nas várias dimensões individuais poderá ser capaz de alterar hábitos e sentimentos que promovam um estilo de vida mais saudável.

Do ponto de vista do arquiteto e do urbanista, os resultados mostram o caráter permanente e condicionante do planeamento da estrutura da cidade e da sua ocupação metropolitana, condicionando as principais deslocações. No entanto, a escala do bairro e da sua envolvente, passíveis de alterações pontuais e de “cosmética”, podem influenciar a perceção individual, criando sensações de bem-estar e adquirindo uma maior atratividade. A importância das várias escalas reforça a discussão sobre as várias teorias urbanas testadas por arquitetos como Le Corbusier (Corbusier, 1964) e Frank Lloyd Wright (Wright, 1932) relativamente à forma como as cidades devem ser desenvolvidas e ocupadas. No entanto, os resultados confirmam a importância da dimensão urbana, explorada e defendida por figuras como Jane Jacobs (Jacobs, 1963), Kevin Lynch (Lynch, 1960) ou Jan Gehl (Gehl, 1987), no que respeita à importância da escala da rua e do desenho urbano para promover atividades que tornam esses locais atrativos e memoráveis, não só para quem vive, mas para quem visita.

As conclusões são importantes para a compreensão da área de estudo, ligando-se saúde e urbanismo, e permitem lançar questões de análise para investigação futura que podem ter um papel significativo num desenho das nossas cidades que contribua para a saúde e bem-estar dos seus habitantes.

A tese cumpre os objetivos que foram definidos. Contudo, é importante reconhecer que são mais as questões e dúvidas levantadas do que aquelas que foram respondidas. A tese tem como ponto de partida a complexidade dos temas envolvidos, como a questão da saúde, e também a da própria cidade. Os resultados comprovam essa complexidade, sugerindo ainda novas questões, o que do ponto de vista da investigação é extremamente interessante, mas, na ótica de quem intervém no território, torna mais difícil justificar a eficácia de uma intervenção relacionada com a saúde da população. Na investigação científica, um dos objetivos mais frequentes é encontrar a causalidade entre factos e acontecimentos. Neste caso, e mesmo tirando partido dos vários indicadores e ferramentas estatísticas, este objetivo é extremamente difícil de alcançar. No caso da saúde, esta relação de causalidade é fundamental para avaliar o impacto de determinada intervenção ou orientação médica. No ponto extremo, estão as metodologias usadas para avaliar a eficácia de produtos farmacêuticos recorrendo a ensaios clínicos. Não obstante, devido ao desenvolvimento tecnológico e à disponibilidade de grandes volumes de dados no contexto das cidades inteligentes (*smart cities*) e à criação de *Digital* Twins, torna-se mais tangível a possibilidade de aferir essa causalidade. Por outro lado, para a definição de políticas públicas e intervenções no território é exigida a comprovação destas relações de causalidade, de modo a aferir a sua eficácia (OECD, 2014).

Obter uma relação de causa entre o impacto das características do ambiente construído e a saúde implicaria um controlo rigoroso de todas as variáveis envolvidas. Por exemplo, o controlo das questões biológicas do indivíduo, como doenças existentes, hábitos alimentares, atividade física, etc, e também a mobilidade diária que resulta no contacto com diferentes contextos ambientais teriam de ser analisadas. Como sugerido por Kwan, (2012) existe uma incerteza temporal relativamente à duração em que os indivíduos experimentam as influências contextuais ao longo do seu dia, mas também ao longo da sua vida. As diferentes escalas e contextos avaliados na Área Metropolitana de Lisboa podem ter um impacto diferente em cada indivíduo face ao tempo que este passa em cada um dos contextos medidos na AML. Isto é particularmente importante tendo em conta as disparidades urbanas e socioeconómicas da AML.

As dificuldades encontradas na modelação estatística sobre o contributo das diferentes escalas urbanas para influenciar a saúde mental pode estar relacionada com esta questão de diferentes contextos urbanos ao longo do dia para influenciar os estados de saúde. Os dados testados avaliam as características do local de residência. Porém, a duração do contato com este contexto poderá ser muito menor do que o contacto com o local de emprego, por exemplo.

Os recursos são finitos e a delimitação de objetivos claros e tangíveis permite definir metas a alcançar face a esses mesmos recursos. Contudo, a tecnologia e a disponibilidade de ferramentas e dados, que permitem avaliar em melhor detalhe a questões individuais e de contexto, são cada vez em maior quantidade e mais acessíveis, reduzindo os recursos necessários. A aprendizagem e a experiência adquiridas ao longo da investigação permitem um conhecimento mais claro das capacidades e limitações, o que se revela útil para o desenvolvimento de propostas de investigação exequíveis, que se poderão traduzir num pós-doutoramento ou projetos de investigação desenvolvidos nas instituições que apoiaram este doutoramento.

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9 Anexos

LISBON

SPACES OF DIALOG FOR PLACES OF DIGNITY:

Fostering the European Dimension of Planning

AESOP

ABSTRACTS BOOK

Walkability over time: An historical evaluation of Lisbon’s walkability since 1775

Abstract

Walkability is a concept that evaluates the characteristics of the built environment that promote walking. Walkability is a complex concept involving aspects of urban design, accessibility, safety, security, among others. Several walkability indexes were created to measure these characteristics. One component of this evaluation frequently used is the network connectivity, which is strictly dependent of the network design. This component of the walkability index has shown a significant relationship with walking in several cases studies across the world. However, most studies analyze the connectivity of the network as it is nowadays, without properly considering the time in which it was built, and therefore understanding how it evolves over time.

The goal of this article is to analyze the evolution of the walkability of Lisbon’s street network using four connectivity indicators, namely node density, pedestrian shed ratio, intersection density and average link length, and associate them with the planning and politics regulations existent in several expansion moments of the city. The indicators were calculated for a floating catchment area of 500 meters for each node of the network. We have focused our analysis in the period between 1755, where a major earthquake has destroyed an important part of the city, and nowadays. Six moments were defined for our analysis: 1800, 1850, 1900, 1950, 1970 and 1990. A shorter division was defined after 1950s due to the known higher expansion of the city after this moment. The actual road network of the city was used as reference for all periods, considering its extension in each moment, through its confrontation with historical maps.

The most important results show a consistent decline of walkability since 1755, visible in all chosen indicators. The two periods in which walkability has declined the most has been the late 19th century, in which large blocks have been developed in several areas of the city, and after 1950, in which a car-oriented pattern has decreased the walking route directness. The historical center systematically appears as the place with higher walkability.

These results are valuable to understand the good example of projects and politics in the city of Lisbon and, maybe, to work as a reference in new expansion or reconfiguration of urban projects. Additionally, it raises the question of which maximum walkability is possible to achieve, given the actual urban design rules and regulations.

9.1 Lista de comunicações

“A distribuição socioeconómica considerando os indicadores de caminhabilidade o caso da Área Metropolitana de Lisboa”. In 16º Encontro de utilizadores ESRI Portugal, 2019, Lisboa.

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"A relação entre o walkability e a saúde na Área Metropolitana de Lisboa – a sua relação direta e indireta." In XI Congresso da Geografia Portuguesa, As dimensões e a responsabilidade Social da Geografia, 2017, Porto.

“The relationship between walkability and health outcomes in the Lisbon Metropolitan Area.”14th International Conference on Urban Health - Health Equity: The New Urban Agenda and Sustainable Development Goals, 2017, Coimbra, Portugal;

“Walkability over time: an historical evaluation of Lisbon’s walkability since 1775.” 30th annual AESOP 2017 Spaces of Dialog for places of Dignity: Fostering the European Dimension of Planning, Lisbon, Portugal;

“Walkability and health – the relationship between built environment and the population’s health status in Lisbon”, 3.ª Semana da Inovação da ULisboa, RedeSaúde, 2017 Lisbon, Portugal;