Travel-time in a grid: modelling movement dynamics in the “minute city”

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Abstract. The concept of the 15-minute city has gained growing attention as a sustainable urban development model aimed at improving people's quality of life while reducing environmental footprint from urban transport demand. Effectively implementing this concept requires urban analysts and planners to assess the distribution of urban functions and propose actions that promote equitable access to services within a reasonable commuting time, primarily using soft mobility modes. However, there is currently no consensus on modelling principles and methods for producing reliable minute-city representations. Additionally, there is uncertainty about the spatial, positional, configurational, and socioeconomic parameters to consider in such models. This paper starts to address this significant knowledge gap by tackling the often-overlooked issue of examining the implications of technical modelling decisions on minute-city evaluations based on an isochrone analysis. One such choice is selecting an ideal point from which to calculate the 15-minute travel radius, as it determines the area where functional centres should be located. The paper conducts a sensitivity test on selected key steps of a typical 15-minute city modelling process, using Rome as an illustrative case. The results shed light on the impact of technical decisions on the outcomes of the 15-minute city analysis. This study provides initial insights and recommendations for developing more robust 15-minute city models. It emphasises the importance of technical modelling steps in determining the mapping outputs which support the assessments of 15-minute cities.

Keywords: 15-minute city, Urban modelling, Urban analysis, Grid-based method, Isochrones, Sustainable Development.

1 Introduction

The Minute-City (MC) concept provides the principles for a citizen-centric model of sustainable urban development, which has gained increasing consideration since the
COVID-19 pandemic and in response to the ongoing climate change crisis. While the term "minute city" was only recently proposed by Carlos Moreno [1] as part of a new plan for Paris, the underlying concept of a people-centred, compact, diverse, and liveable city has been alive in the neighbourhood and city planning discourse since the 60’s [2] and even earlier [3]. Hence, the idea of the MC has gradually developed over time through different sources and academic contributions, including Christopher Alexander [4] and Jan Gehl [5], acquiring a new digital dimension in its latest conceptualisations. This digital dimension suggests the incorporation of the MC concept in smart city strategies, where technological advancements, including the availability of industry 5.0 technologies, are expected to enable its effective actualisation [6].

At its core, the MC concept, also known as new “chrono-urbanism” [1], aims to improve people’s quality of life, including their health and well-being, promote opportunities for active travel (such as walking and cycling) [7], and provide increased social interaction and cohesion. This, in principle, is rendered possible by the availability of key urban functions and amenities – such as healthcare, education, retail, and leisure facilities – at locations placed within physical proximity (e.g., a walking radius of 15 minutes) from where people live, study and work. The 15MC model rejects Le Corbusier's belief that city’s functional separation in the ‘living, working and recreation’ rationalist triad, and speed, lead to urban success [8] and instead emphasises the importance of reducing the need for long-distance travel in daily urban life. To achieve this, minute cities aim to promote density, diversity, efficiency, and public engagement through polycentrism, circularity, mixed-use and low-carbon developments, plus ubiquity of key services and resources.

Within this framework, digital solutions and data about venues’ locations, available routes, and flows, that can be more easily produced using technology and social capital, are crucial in creating the necessary socio-technical assemblages to achieve the 15MC vision. In fact, both access to meaningful data/information and effective governance structures are essential for planning the 15MC, as clarified in [6]. A similar point can be made in relation to 20 Minutes Neighbourhoods (20MNs), an equivalent concept adopted in Australia that allows for longer travel times, as stated in [9].

In the aftermath of the pandemic, many global cities in Europe and around the world – including C40 cities belonging to the Climate Leadership Group [10], such as Hildago’s Paris, Colau’s Barcelona, Sala’s Milan, Ottawa (2019’s 25-year growth blueprint), Melbourne (2017-2050 plan), and Portland (Climate Action plan 2018) – have begun experimenting with the 15MC concept. Since the planning of minute cities requires that decision-makers have access to appropriate MC models and representations, there has been a rise in the number and variety of MC’s models and analysis tools in recent years [9,11,12,13]. Existing models represent the 15-minute city's functional characteristics in different ways, including via isochrone maps [12] and network analysis [13], which often converge in grid-based methods [11,14]. These representations rely on factors such as data availability and analysis scale, plus tend to focus more on services’ provision (e.g., when centring the analysis on urban functions or on road network configurations) than on peoples’ experiences and habits, neglecting some important aspects of MC conceptualisations that have to do with softer aspects of urban life. Moreover, they are often developed from a colonial perspective which does not
always account for local planning history and issues of equity and justice [15]. Even when the choice of a specific MC representation is context-aware and aligned with local policy objectives, the application of this concept still faces practical challenges and ambiguities in accurately modelling minute cities and standardising their representations. Hence, it is crucial to give due attention to these frequently neglected technical aspects and take proactive measures to address them effectively, as only by doing so can we produce meaningful evidence to inform decision-making.

This paper seeks to address this criticality by providing an overview of key methodological challenges in 15MC assessments, with a focus on MC modelling and representation issues in grid-based isochrones’ analyses. The scope of the analysis is restricted to walked distances although in future studies the analysis could be expanded so as to consider other soft mobility modes. Sections 2 and 3 of this paper will respectively identify and provide tangible examples of the main steps and limitations of modelling methods used to represent 15-minute cities and their functional characteristics. Section 4 will then offer urban analysts some preliminary insights into the models' inherent criticalities and applicability. In the end, the paper will open a discussion which intends to stimulate future research on MC modelling for evidence-based (as opposed to merely data-driven), as well as more transparent and robust 15MC planning.

2 Examining the methodological challenges of MC Assessments

Fig. 1. Grid-based minute-city modelling workflow using isochrones. The diagram represents key activities (colour-coded) and process’ gateways (X equals “or”, + equals “and”).
Modelling and representing 15-minute cities pose numerous methodological challenges. While current assessments tend to employ multi-level spatial analyses to address complexities [6,9,12,13,14], methods and, above all, representations are frequently lacking standardisation. For instance, [14] proposes an analysis that maps resident and workplace density, allowing for the identification of variations in inhabited areas. It evaluates the availability of different essential services and assesses walkability using a squared grid structure. Factors such as location, road-network, travel time, and urban morphology are considered in this assessment. In comparison, [12] employs a hexagonal grid to map access to essential services based on different mobility modes. Its approach helps identify the most accessible areas within a 15 minutes’ radius. These studies are exemplary, as they raise three distinct issues regarding the robustness of the underlying modelling process.

The first issue (I) concerns the choice of the locations used to establish the boundaries of the isochrones’ 15-minutes radii (hereafter referred to as barycentres). In grid-based assessments, these locations are indirectly determined by the chosen tessellation and its resolution, which can impact the calculation of travel-times. In fact, different grids can yield varying groups of barycentres and isochrones. The second issue (II) involves the definition of the isochrones and the estimation of walked travel time. Different tessellations (and software applications) can result in varying isochrone densities, leading to a different coverage for areas of a similar size. Moreover, most MC isochrone models typically consider the average travel speed of an adult, disregarding potential variations due to factors such as age and other individual characteristics [16,17]. The third issue (III) pertains the classification of urban functions in static proximity analyses, which emerges as a significant distinction among MC models. This issue becomes particularly critical when considering the inherent limitations of using static MC representations, as opposed to dynamic ones, to reproduce temporal urban patterns. These three issues lie at the core of this investigation, while modelling variables that are more theoretical in nature are beyond the scope of this study.

Figure 1 illustrates the modelling workflow on which the presented study is based. The main steps are shown in the image using different colours to distinguish between regular modelling activities, theory-informed decisions, and technical modelling choices, where the latter represent the focus of this work. As Figure 1 also illustrates this study’s materials and methods, the image includes the modelling tools and datasets used throughout the investigated process. In particular, it shows that the maps used in this paper to calculate the isochrones and the functions’ locations were extracted from the OpenStreetMaps (OSM) [18] geodata repository and modelled in the QGIS suite [19], using official ISTAT (Italian national institute for statistics) data for the administration boundaries. Two digital services, namely Iso4App and ORS tools, where then used to enable comparative assessments between different isochrones’ generation processes in the selected case study area.

The location used for the presented sensitivity test is the Centocelle neighbourhood, in the V Municipality of Rome. The regeneration of Centocelle as a 15-M neighbourhood is, in fact, at the centre of the on-going strategy of the Capitoline Administration to reduce social and geographical inequalities [20]. This mostly residential area takes its name from the nearby archaeological park (separated from it by Via Casilina), which
serves as a vital green area for its inhabitants. Centocelle’s development commenced in the early 1900s with the establishment of its namesake airport, which is no longer operational. In the 1940s it was home to industrial workers, artisans, small traders, farmers, and tram drivers [21]. Today, Centocelle remains a working-class district, caught between gentrification and social decline. It is served by a few tram lines, the Roma-Giardinetti railway, and the metro line C, which has been a pivotal addition since 2014.

3 Untangling MC modelling ambiguities

3.1 Tessellation of the 15-minutes city and barycentres’ location

A methodological challenge of representing the 15MC in a grid is determining the most suitable approach for capturing variations in the availability of urban functions within and across urban areas. The selection of grid tessellation methods can lead to diverse outcomes in terms of barycentres’ distribution, resulting in distinct coverage areas for the 15-minute travel radius and, subsequently, different MC maps.

When addressing this issue, there are two aspects that must be considered: a) the size, and b) the form of the grid tessellation; plus, c) the computational complexity of calculating the 15-minute travel-time radii, which depends on the choices made regarding the size and form of the grid. To demonstrate the extent of these challenges, we created several tessellations in GIS on a base map representing the urban area of Rome, Italy (Fig. 2). We explored three different grid forms: square, hexagonal and voronoi polygons. For the square and hexagonal tessellations, we examined two different sizes (1 km² and 500 m²), for a total of 5 grid structures, from which we extracted the barycentres of each individual cell.

The results of this exploration reveal that the choice of tessellation size and form has a significant impact on the distribution of the barycentres, with minimal overlap observed between different groups (Fig 2). Larger grid sizes tend to cover a greater area, yet, depending on size, grid boundaries can be wider than those of the 15-minutes isochrone calculated inside it (especially in voronoi tessellations). Therefore, larger tessellations may fail to capture certain urban functions within the cells, not accurately reflecting the overall accessibility, or services’ coverage, of that grid space. Random tessellations, such as voronoi polygons (Fig. 2) may have similar issues. Smaller grid sizes offer advantages by generating a higher number of barycentres and provide a better overlap among the isochrones (Fig 2; Fig. 3a), which may lead to a more precise assessment of functions’ coverage. However, the barycentres’ position is still influenced by the grid form. For instance, barycentres derived from 500m2 squared grids will differ from those derived from hexagonal grids of the same size, resulting in varying outcomes and overall territorial coverage. While smaller grids improve precision, there is a trade-off between the complexity of the tessellation and the computational burden it imposes. Intricated tessellations with smaller grid cells increase the computational requirements for calculating barycentres and, more importantly, isochrones. This can pose challenges in terms of processing time-lapses and resource allocation, particularly when analysing large-scale or real-time scenarios. This issue also highlights the difficulties in conducting a citizen-centric analysis, where accessibility should be
measured based on factors such as dwelling distribution, daily habits, population density, and demographics, since dynamic spatial representations demand greater computational efforts. In summary, the choice of methods for tessellation and establishing the 15-minute travel-time radius is a complex task affected by factors such as grid size and form, plus other non-accounted factors related to a citizen-centric approach.

Fig. 2. Five tessellations of Rome. In the zoom the barycentre locations, distinguished using the corresponding tessellations’ colours, and the boundary indicating the location of Centocelle.
Different tessellation methods will inevitably result in distinct coverage areas for a 15-minutes travel-time, effectively creating different minute cities based on the selected approach. In the next section we will delve more into this aspect and examine the variations that result from different isochrones’ construction methods.

3.2 Isochrones’ size, construction methods and demographics

![Fig. 3. Comparison between 15-minute travel-time isochrones: a) calculated from different tessellated barycentres; b) generated from different applications (ORS Tools & IsoApp) for a same barycentre and with different walking speeds.](image)

The fact that various tessellation approaches yield distinct groups and distributions of barycentres within an urban area (Fig. 2), by extent, raises another methodological challenge, i.e., representing spaces that correspond to 15-minute travel within a grid. Since the placement of barycentres differs depending on the chosen tessellation, the resulting coverage of isochrones will also vary across different grids, despite each isochrone representing the same 15-minute travel time in principle (Fig. 3a).

As previously discussed, these variations in isochrone coverage based on different methodological approaches can lead to disparities in determining which grid spaces qualify as a minute city. In fact, depending on the isochrone coverage, which is influenced by the grid size, certain areas may or may not encompass amenities and services. Moreover, the use of different applications to generate isochrones for the same area can result in distinct representations of the 15-minute travel-time, as depicted in Fig. 3b. Despite utilising the same input data (same barycentres), variations in algorithms, road network data, or other underlying settings controlled by the application can lead to discrepancies between the calculated isochrones.

Furthermore, Fig. 3b highlights another issue related to demographics and the representation of walking speeds in chrono-distance. To illustrate it, we modelled the
isochrones for a fixed barycentre considering different age groups’ walking speeds, adapted from [16], with the inclusion of a sub-category for the super-elderly (>85 years) or individuals with mobility limitations, whose walking speed is halved compared to the range of >65 - <= 85 years. The results obtained by considering different walking speeds based on individuals’ age for the same barycentre highlight significant differences in the extent of the isochrones (Fig. 3b). This implies that the covered distance within a 15-minute travel time can vary substantially among different demographic groups, even within the same area. Naturally, the coverage of amenities and services will also differ accordingly. Hence, it can be argued that there exist multiple 15MCs within a "standard", or average-individual centred, 15-minute city [17].

Once again, these findings emphasise the need for a more considered approach in representing 15-minute cities, particularly from a citizen-centric perspective. As previously highlighted, the lack of standardisation in determining barycentres and, consequently, isochrones can pose challenges when comparing cities, or "cities within cities", and when aggregating findings from studies that employ different grid structures. This absence of a consistent benchmark makes it difficult to establish a universal representation of what constitutes a 15-minute city. Thus, decision-making processes that solely rely on baseline isochrones may potentially lead to exclusive policies or inconsistent planning decisions, as different tessellation approaches and isochrones’ calculation systems may prioritise certain areas or demographic groups over others.

### Table 1. Walking speeds in accordance with demography.

<table>
<thead>
<tr>
<th>Age groups (in years)</th>
<th>Estimated walking speed</th>
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<tbody>
<tr>
<td>&lt;= 30</td>
<td>4.8 km/h (1.34 m/s)</td>
</tr>
<tr>
<td>&gt; 30 - &lt;=60</td>
<td>4.5 km/h (1.26 m/s)</td>
</tr>
<tr>
<td>&gt; 60 - &lt;=65</td>
<td>4.3 km/h (1.21 m/s)</td>
</tr>
<tr>
<td>&gt; 65 - &lt;=85</td>
<td>3.4 km/h (0.95 m/s)</td>
</tr>
<tr>
<td>&gt; 85</td>
<td>1.8 km/h (0.5 m/s)</td>
</tr>
</tbody>
</table>

#### 3.3 Classification of urban functions

Another aspect that must be considered in the context of 15MC analyses, where methodological inconsistencies are often found among studies [6,14,15,17], concerns the classification of urban functions. The way in which these functions are grouped into different classes or macro-categories can lead to significant differences into defining which grid spaces correspond to a minute city. Different studies or analyses may adopt distinct classification schemes based on their specific goals, research questions, or available data. These classification systems can vary in terms of their strictness, the types of activities included, and the criteria used for the classification. For instance, in a 15MC model proposed by [14], the threshold for essential services is set at 7 out of 9 macro-categories of services, which include food stores, general retail, cultural venues, educational facilities, green spaces, hospitality, healthcare, sports facilities, and a 'other' category. This issue mainly stems from ambiguities in interpreting the generic six essential urban social functions (living, working, supplying/commerce, caring/healthcare, learning/education, and enjoying/entertainment) proposed by Moreno,
first in [1] and then in [6]. The attribution of different functions to the same service becomes possible, introducing an element of arbitrariness in the classification process. For example, shops can be classified under both ‘working’ and ‘supplying’ functions, depending on the perspective of employees and customers, respectively.

As mentioned in Section 2, in our case study, the locations of amenities (plus ‘shops’) were extracted from the OSM geodata repository. To align with Moreno’s classes, we propose two different classifications of OSM data (presented in Table 2), which consider the following categories [22]: sustenance, education, transportation, financial, healthcare, entertainment, arts & culture, public service, facilities, and waste management. From the list we exclude living and working due to ambiguities in considering them as functions to be mapped, as they may rather correspond to the barycenter’ locations. Our “strict” classification considers only the OSM macro-categories that directly correspond or overlap with Moreno’s proposed classes. Conversely, the “wide” classification includes additional categories that do not directly align with Moreno’s classes but, in the authors’ opinion, should not be disregarded.

**Table 2.** Stricter and wider urban functions’ classifications based on Moreno and OSM.

<table>
<thead>
<tr>
<th>Functions</th>
<th>OpenStreetMap Categorization</th>
</tr>
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<tbody>
<tr>
<td>Commerce</td>
<td>Shop</td>
</tr>
<tr>
<td></td>
<td>Sustenance</td>
</tr>
<tr>
<td></td>
<td>Financial</td>
</tr>
<tr>
<td>Healthcare</td>
<td>Healthcare</td>
</tr>
<tr>
<td>Education</td>
<td>Education</td>
</tr>
<tr>
<td>Entertainment</td>
<td>Entertainment, arts &amp; culture</td>
</tr>
<tr>
<td></td>
<td>Public service</td>
</tr>
<tr>
<td></td>
<td>Facilities</td>
</tr>
<tr>
<td></td>
<td>Waste Management</td>
</tr>
<tr>
<td>Transportation</td>
<td>Transportation</td>
</tr>
</tbody>
</table>

**Fig. 4.** Amenities and services distribution in accordance with the different classification methods – a) strict classification; b) wide classification – colour code associated to Table 2.
During the process of classifying amenities from the OSM data a number of issues emerged in relation to the use of different categories as some amenities were incorrectly assigned or not assigned at all. Moreover, the category ‘others’ was excluded from this study because of it was too general for including it directly in the analysis.

The adoption of different classifications, namely the “strict” and the “wide”, results in distinct distributions of amenities, as depicted in Figure 4. Consequently, certain activities or macro-categories may be excluded or treated differently in different analyses. This omission or variation can have implications for the proper consideration of functions’ availability in areas within the 15-minute radius. For instance, if a particular study fails to include public transportation stops or bike sharing stations as separate activity classes, the resulting analysis may not adequately capture the accessibility and availability of these amenities within a 15-minute walking distance.

4 Towards more accurate representations of the 15-minute city

Moreno highlights that the concept of “chrono-urbanism” may appear arbitrary, as it involves the selection of specific timeframes as reference for planning. However, he emphasises that the approach naturally lends itself to place-based customisation and adaption, including in selecting the time boundary for analysis [6]. Nonetheless, this paper argues that it is essential to combine this flexibility with methodological rigour, to ensure thorough assessments and produce reliable evidence for informing planning decisions. For instance, for each considered time frame, ensuring the consistency of the corresponding MC model becomes crucial to enable reproducibility and comparisons across different MC representations. Additionally, modelling choices should be carefully justified, including based on the characteristics of the study area and the specific planning goals that drive the modelling activity.

This paper showed that creating accurate MC representations is a (computationally) complex undertake, requiring a series of technical decisions which are generally made without the support of a defined methodology and/or adequate guidance. As a result, MC modelling choices sometimes are dependent of the researcher’s perception, which may be subjective. Addressing this issue requires careful consideration of technical modelling decisions and transparency regarding critical steps taken to produce MC representations. We focused our experiments on evaluating grid-based methods and identified four noteworthy variables: (I) grid tessellation choices, influencing the isochrones’ barycentre location; (II.a) software application pick, affecting isochrones’ construction; (II.b) speed selection for travel-time calculations (e.g., walking); (III) classification rules’ adoption for mapping urban functions against mapped amenities.

With specific regard to point I, our study evidenced the existence of a trade-off between tessellation size, precision, and computational complexity affecting the location of the barycentres used in the analysis. Moreover, it showed how different classification rules can affect MC representations (point III).

In addition to these four technical elements, we identify other modelling variables that are primarily theoretical, such as the formula used to calculate the final MC score.
While this aspect falls outside the scope of the present paper, its exploration represents a promising direction for future research.

The paper advocates for a greater availability of information regarding MC modelling. This issue stems from the inadequate tracking of technical decision-making history and has not received full attention from the scientific community thus far. Nonetheless, it undermines the value of MC models in guiding the planning and design of minute-cities, consequently posing a risk to the attainment of connected sustainability goals. It is, hence, imperative that researchers and practitioners ensure greater transparency in MC modelling by better documenting technical choices. This paper takes initial steps in identifying gaps in technical workflows’ documentation that can impact MC modelling results (and the subsequent planning processes they inform), however, further research efforts are needed to establish standardised methodologies and guidelines for producing robust grid-based representations of minute-cities through isochrone analysis.

In this regard, conducting a review of workflows and technical choices adopted in different MC studies would shed light on best practices and help identify areas for improvement in MC modelling. Such explorations may examine elements such as the algorithms employed, and settings utilised, when operating MC modelling tools. To this end, comparing MC models’ outputs with empirical data and/or conducting more comprehensive sensitivity tests can help develop protocols to increase the robustness of the isochrone generation process. In other words, it is essential that technicians have a comprehensive understanding of the underlying assumptions, and limitations, associated with the use of different software tools for generating isochrones and that the accuracy and reliability of MC assessments is ensured. To this end, it is crucial to initially verify, and if possible, validate, MC modelling results (e.g., using ground truth information), scrutinising and adjusting the settings and/or algorithms used in spatial computations when significant discrepancies are identified.

The absence of standardised modelling protocols imposes significant limitations on the application of MC models, hinders synchronic comparisons, and can indirectly foster the formulation of exclusive policies and inconsistent planning decisions. Hence, it is crucial to undertake concerted efforts towards standardisation, including by bridging the gap between the planning practice and software development communities, to effectively address the existing challenges in MC modelling and representation. This entails establishing shared modelling protocols, algorithms (across various software applications), and standardised data inputs, all of which can substantially enhance the consistency and reliability of grid-based MC assessments focused on travel-time estimates. Ultimately, advancing research, fostering collaboration, and promoting knowledge sharing, can elevate the quality of evidence generated through spatial analysis, leading to better-informed decisions in MC planning.

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References