Comparing standard and low-cost tools for gradient evaluation along potential cycling paths

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Abstract: - Promoting the use of non-motorized modes of transport, such as cycling, is an important contribution to the improvement of mobility, accessibility and equity in cities. Cycling offers a fast and cheap transportation option for short distances, helping to lower pollutant emissions and contributing to a healthier way of life. In order to make the cycling mode more competitive in relation to motorized traffic, it is necessary to evaluate the potential of alternatives from the perspective of the physical effort. One way to do so consists of assessing the suitability of locations for implementing cycling infrastructures. In this work, four tools to determine the gradient along potential cycling paths are compared. Furthermore, an evaluation of the reliability of some low-cost tools to measure this parameter was conducted, by comparison with standard measurements using cartographic plans, on a field case study applied to the city of Braga, Portugal. These tools revealed a good level of accuracy for the planning stage, but proved to be less reliable for use in design.

Key-Words: - cycling; cycling planning; gradient; low-cost tools.

1 Introduction

Urban problems related to the excessive use of motorized vehicles are very common in medium and large cities. Most of those problems occurs in urban areas where the transport system no longer can satisfy the numerous requirements of urban mobility. Traffic congestion, parking difficulties, longer commuting, public transport inadequacy, difficulties for non-motorized transport, loss of public space, high maintenance costs, environmental impacts and energy consumption, accidents and safety, land consumption, and freight distribution are some of the most notable urban transport problems [1][2]. Part of the technical and scientific community, as well as global society, are aware of the seriousness of these problems. For that reason, there is a bigger mobilization and a larger interest in discussing projects that aim to provide more sustainable and healthier mobility patterns to urban citizens. In this context, Banister [3] has discussed the principles of the sustainable mobility paradigm, outlining seven key elements in promoting the public acceptability of sustainable mobility (information, involvement and communication, packaging, selling the benefits, adopt controversial policies in stages, consistency between different measures and policy sectors and adaptability). Hull [4] studied transport decision-making in five local transport authorities in England, exploring the joint working practices in some public policy sectors that influence accessibility patterns. More specifically, cycling is explored has a factor for defining and enhancing the sustainability of urban mobility [5][6][10][11]. On the other hand, cycling is promoted as a beneficial activity for people health, associating it to an active way of travelling [7][8][9][12][13]. The European Commission is actively taking part in this quest for changing the transport paradigm, encouraging and promoting the use of cycling in urban mobility, a transportation mode she defines as cleaner, more economical and more equitable than motorized vehicles [14].

In developing countries and on countries where cycling have a low use, one of the community requests for cycling usage in cities is the improvement or adaptation of road infrastructures, namely through the creation of cycle lanes or cycle tracks, depending on the level of segregation. To analyze this, planning studies and projects about the introduction of cycling infrastructures must be developed and appraised.

In earlier stages, the existence of fast and reliable low-cost tools for assessing a project feasibility and development of cycling networks is essential due to the frequent lack of resources to conduct studies on this subject by local authorities in times of economic recession. However, it is essential to be aware about the accuracy of data gathered using different low-cost tools.

One of the main issues that have been raised in questionnaires to local populations in Portugal is the gradient of roads or paths in consolidated urban areas. This is also a common factor referred in many other studies [15][16][17][18][19]. Thus, the assessment of the suitability of a terrain or road to receive a new cycling infrastructure is based on the evaluation of the longitudinal gradient of a certain stretch, which actually is a factor that highly restrains the mobility of a cyclist and a key parameter for planning and design phases of a cycling network.

In this paper are going to be presented some examples of classes of gradients related with cycling conditions that should be used as references to implement a cycling network, showing the relevance that this parameter has in planning and designing of cycling infrastructures.

In order to achieve a cheap and fast evaluation of the possibility to introduce a cycle route in certain urban area, some tools can be used without recurring to topographic surveys or cartography, such as: Google Earth from the software company Google, a digital inclinometer (DMN 120 L from Bosch Professional), and a Hand Held Laser Distance Measurer (DISTO D8 from Leica), which also performs as a digital inclinometer, that were analyzed and compared in an application developed in a central area of the city of Braga, North of Portugal. In order to assess the reliability of this set of tools a comparison was done with an available cartography of the application area, which was used as a reference element for accuracy evaluation.

2 Gradients for cycling

The first step to implement a cycle lane in a given area is to perform a geomorphological analysis, i.e., a terrain evaluation and the assessment of its ability to be used by cyclists. In this case, the longitudinal gradient of existing roads has a major influence [20].

Cycle lanes should be as flat as possible, while the potential risk of accident for cyclists travelling in stretches with steep inclination at high speeds is very high. On the other hand, the difficulty of steering a bike during a steep ascent stretch, especially when adopting the maximum allowable gradient values in a two-way infrastructure may also increase the risk of accident. Gradients greater than 5% should not be considered unless there is no other alternative. It is also important to avoid tight curves, especially small corner radius, especially when gradient is steep (above 5%). If a curve was designed at the end of a steep descendent stretch, an additional lane width should then be provided, on the other hand should be clearly thought an escape zone or an adjacent recovery zone outside the curve area [21].

A cycling route for a vast majority of users will be more attractive when the longitudinal gradient of the terrain or roads is low [22]. In general, cyclists will get out of their way to avoid climbing a steep stretch of a road or path. By other side, they will try to avoid conflicts with motorized traffic, especially when cycling speed is much lower than the motorized vehicles, and as well as because they will not be able to keep their pace constant [23].

Table 1 show gradients commonly used and recommended by the Center for Studies and Landscape Architecture of Lisbon [24] for the analysis of the geomorphological suitability of a terrain for the cycling mode.

Table 1 - Terrain suitability for cycling [24]

Gradient	**Terrain characteristics**	**Level of suitability**
0-3%	Flat	Excellent for cycling
3%-5%	Low gradient	Satisfactory for cycling but only for short distances, paths should be provided with resting areas
5%-8%	Medium gradient	Unacceptable for cycling, especially for long distances Acceptable for short connections
8%-10%	High gradient	Unacceptable for cycling Acceptable for short connections

Table 2 presents the acceptable gradients for short distances travelled in ascending sections, according to The American Association of State Highway and Transportation [25].

Table 2 - Gradient restrictions and lengths [25]

Gradient	**Grade length**
5% - 6%	for up to 240m
7%	for up to 120m
8%	for up to 90m
9%	for up to 60m
10%	for up to 30m
≥ 11%	for up to 15m

The AASHTO guidelines also addresses that a terrain with more than 3% of gradient is not recommended for cycle lanes with unpaved surface, either due to handling issues as well as for drainage problems. The national transport agency for Scotland [22] specifies that sections with a gradient greater than 5% should be designated as ramps. Table 3 shows the recommendations for maximum values of gradients according to the length of a section.

In the Guide to Road Design Part 6A, Pedestrian and Cyclists Paths, from AUSTROADS [21], desirable and acceptable gradients according to the length of the cycle sections can be found. Thus, the following items should be considered on cycling planning:

i. For gradients above 3%, the acceptable length of the ascending section decreases rapidly, making this value the maximum desirable gradient to be used on roads. Although in practice, there are cases where it is impossible to maintain the maximum gradient below 5%, giving no other choice to designers but to adopt higher gradients;

ii. In cases where 3% as maximum gradient cannot be kept, it is preferable to limit the gradient to a maximum of 5% and to provide flat sections of reduced extent (about 20 meters) at regular intervals, offering resting areas for cyclists, both in up and down directions.

iii. In some cases, it may be difficult to guarantee these gradients, for example, when a route follows a river or when a connection between pathways must be implemented nearby a very steep hillside. It should also be noted that before a long steeply ascent, it is more acceptable to have a descent than a slightly ascent or a plane stretch.

It is evident that the guides and references cited above recommend as a desirable longitudinal gradient for very long sections a value under 3% and keeping the maximum gradient under 5%. It was also observed that, when these limits cannot be kept along the entire path, i.e., when a very high gradient is found, this steep section should be as short as possible and effort mitigation techniques must be implemented, such as escape areas for cyclists resting.

Table 3 - Gradients according to the length of a section (adapted from [22])

Location	Gradient	Length
General Cycle facility	0 - 3%	Any
	3 - 5%	Any. Landings are required
	5 - 7%	10 m. max. Landings are required
	≥ 7%	5 m. max. Landings are required
On the immediate approach to priority junctions	3% (max. allowed)	Over a minimum approach distance of 6 m.
On the approach ramp to a bridge or subway	0 - 3%	Any
	3 - 5%	Any. Landings are required
	5 - 7%	10 m. max. Landings are required
	≥ 7%	5 m. max. Combined with treatment to control speeds. Landings are required

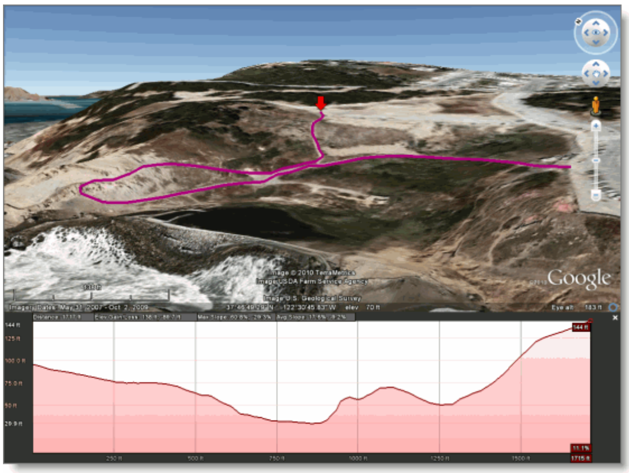
3 Some tools for measuring gradient of terrains and roads

3.1 Google Earth

Google Earth is nowadays a tool commonly used in various studies due to its intuitive interface and easiness of use and access. It provides a three-dimensional model of the globe, built from a mosaic of satellite images from various sources, aerial images (photographed from aircrafts) and three-dimensional GIS data (Geographic Information System). Altimetry data were collected by the Shuttle Radar Topography Mission (SRTM), an international project led by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space administration (NASA). The SRTM is a radar system that generated topographic profiles of the Earth applying the technique of interferometry. By this way, it was possible to create the first Digital Elevation Model (DEM), at almost a global scale, which can be accessed through the Google Earth interface.

The DEM generates a topographic profile between two specified points, simply by drawing a line between them. Google Earth software provides the average, minimum and maximum gradient, along the whole profile generated between the points. The average gradient of a single section of the street or terrain profile is also available, as shown in Fig. 1.

Fig. 1 - Google Earth Elevation Profile



Source: Google Earth Help (2014)

This feature was used in this study to assess the reliability of this tool, as it will be explained in Section 4.

3.2 Digital inclinometer DMN 120 L professional

Table 4 shows some technical data of the digital inclinometer DMN 120L that was used in the case study.

Table 4 - Main technical data of the digital inclinometer DMN 120L

Length	1200 mm
Electronics measurement accuracy (0º/90º)	± 0.05º
Electronics measurement accuracy (1- 89º)	± 0.2º

This measuring tool is simple to operate: simply standing on the surface, it will indicate the gradient in degrees, percentage or mm/m. Moreover, it has two vials, enabling to be used as a spirit level for horizontal and vertical levelling.

Fig. 2 shows a picture of the digital inclinometer, where the two vials can be seen (one at the right and the other near the centre). Right in the centre, there is an electronic display where the gradient value can be read. In this example, the measured value is 0.0%.

Fig. - 2 Reading gradient value on the digital inclinometer DMN 120L

3.3 Laser Distance Meter DISTO D8

Main tilt measurements data of the laser distance measurer are listed in Table 5.

Table 5 - Main tilt measurements data of the laser distance measurer DISTO D8

Tilt sensor accuracy (2σ) to laser beam	± 0.1º/ ± 0.2º
Tilt sensor accuracy (2σ) to device housing	± 0.1º

The Leica DISTO D8 is a laser device for measuring distances. Furthermore, it can also be used to perform several types of measurements, such as angles and inclinations. To measure gradient, it only needs to stand on a surface and the device will exhibit on the digital display the gradient value in degrees, percentage or mm/m. In Fig. 3, the device can be observed standing on the ground and showing gradient in percentage.

Fig. 2 - Reading gradient value with DISTO D83

A Laser distance measure is an alternative to the traditional tool, the metal tape measures. This device is used to calculate lengths, widths and heights of up to about 200 meters. It is generally considered accurate to within 1 millimeter, when measuring a distance of up to 10 meters. Measuring accuracy between 10 m. and 30 m. may deteriorate to approx. ± 0.025 mm/m, and for distances above 30 m to ± 0.1 mm/m.

To use a laser distance measure, the device should be placed on one end of what is to be measured, and then laser beam must be aimed in a way that it hits an object/surface at the other end. If no wall, pole or surface is available, a target can be set at the spot where the measurement is intended to end. The process is quite similar to using a conventional tape measure, except a laser beam is used instead. Once the laser is considered to be at the right spot, usually a button should be pressed and the device stores and displays on the screen the calculated distance. The calculation is done through precision optics and laser physics using the phase-shift tool, in which a laser hits an object and compares its reflection with the beam sent out, or using the time-of-flight tool in which the time it takes for an optical pulse to reflect back is calculated. Some laser measures enable measuring multiple distances and adding all automatically, to obtain an accumulated value.

Laser measures are normally quicker to use than conventional ones, and may help to avoid inaccuracies that can be caused by a twisted or sagging tape measure. Furthermore, it is easier to read a digital display of the measurement than to count little lines on a tape measure. They also are very useful when measuring high ceilings and other hard-to-reach spaces.

4 Methodology

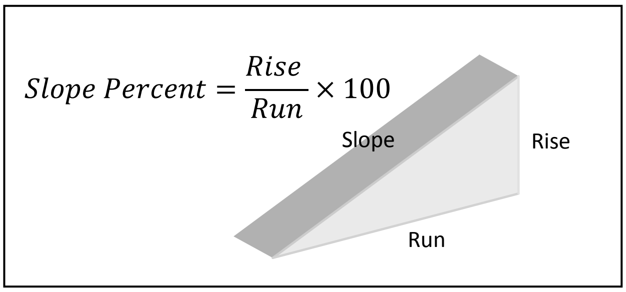
In this section, the methodology describing how to determine the gradient of a road stretch is described for each tool described previously.

On the other hand, in order to collect comparable values that would allow assessing the reliability of the tools, it is mandatory to define previously and to use for all tools the same locations to be evaluated, i.e. the same streets, avenues, squares, ramps and other elements. Thus, streets were divided in homogeneous stretches, considering that the street gradient did not change along it.

4.1 Using contour lines in a topographic cartography

Using topographic cartography is a well known tool to determine gradient. Fig. 4 remembers how the gradient percent calculation is done.

Fig. 4 - Gradient calculation



Equation (1) describes how the longitudinal gradient of a segment (i_i) can be calculated using the coordinates of the endpoints p_i and p_{i+1}.

$$d_i = x_{i+1} - x_i \ , \qquad i_i = \frac{y_i - y_{i+1}}{d_i} \qquad (1)$$

where,

x_i: point p_i abscissa;
y_i: point p_i elevation;
x_{i+1}: point p_{i+1} abscissa;
y_{i+1}: point p_{i+1} abscissa.

After applying equation (1) to all segments of a path, the average gradient of the path (i) can then be calculated.

4.2 Using elevation profile of Google Earth

After drawing or loading a path in Google Earth interface, its elevation profile can be displayed when selecting the option *Show Elevation Profile*. The desired profile appears in the lower part of the viewer (Fig. 1).

In the chart, the Y-axis represent the elevation, and the X-axis corresponds to the distance. When the cursor is moved through the various parts of the Elevation Profile, an arrow moves along the path and displays the elevation (left side of arrow) and cumulative distance (above the arrow). The number displayed as a percentage represents the gradient.

4.3 Using the digital inclinometer and the laser distance meter

With both devices (DMN 120 L and Disto D8), gradient percent must be measured in the same direction of the traffic lane and then the devices must be installed parallel to the road centreline. As the aim is to obtain an average gradient along a path, several measurement points must be included in the campaign. For that reason, a collecting distance must be defined previously, enabling to divide the path in homogeneous stretches and to keep a regular distance between measurement locations [26].

For safety reasons, it is recommended to collect data on sidewalks, when the campaign occurs in roads with traffic.

At the end, the average gradient of the path can be calculated, using gradient values collected on each measurement point that represents a homogeneous path stretch.

5 Evaluating the reliability of the tools in some streets of the city of Braga in Portugal

A practical application was carried out in the city of Braga, which is located in the Minho region at the Northwest of the country. The municipality of Braga has an area of 183.40 km² [27] and it is one of the largest cities of the country with 181494 habitants and a population density approximately of 10000 inhabitants/km² [27]. According to the national Census of 2011 [27], 35% of the city population are between 0 to 25 years old, 54% are in the group age of 24 to 64 years and the elderly represent 11% of the population.

The city has no tradition in cycling but its center has flat characteristics that can be used by cyclists. On the other hand the city is at the moment planning its urban cycling network and it can be seen traffic streams with bikes, which was unthinkable decades ago. However, nowadays Braga has already a nongovernmental organization to promote cycling – “Braga Ciclável”, reinforcing the increasing interest by citizens of Braga in about this issue.

Planning a cycle network for a city requires more than the evaluation of gradients, despite this is a key issue that should be evaluated in as primary stage of the planning process.

In the following sections, the reliability of the "low-cost" tool (Google, Digital inclinometer and the Laser distance meter) is analyzed.

These tools were presented in the previous section and were applied to paths chosen from seven Avenues of a central area of the city of Braga: namely, the Av. *da Imaculada Conceição*, Av. *João XXI*, Av. *João Paulo II*, Av. Robert Smith, Av. *da Liberdade*, Av. *Frei Bartolomeu dos Martires* and Av. Dr. *Francisco Salgado Zenha*. The map of Fig. 5 shows those avenues identified with red markers.

The first practical iteration was to determine the longitudinal gradient of avenues using Google Earth. Then, the obtained value was compared with the gradients calculated from the cartography of this area, where the altimetry was determined by classical topographic surveying.

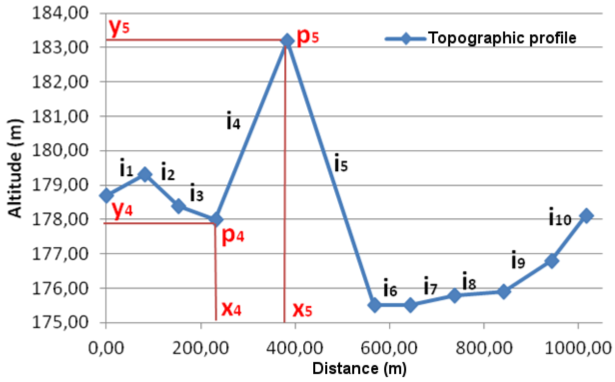
Fig. 5 - Avenues where gradient was calculated

Using Google Earth, the gradient of each road segment was provided automatically by the platform. Nevertheless, Google Earth has a limitation when it comes to places such as bridges or overpasses, since this tool only provides one elevation value. In those cases, such as the Av. *Frei Bartolomeu dos Martires*, it was necessary to divide in two sections to determine the gradient of adjacent stretches of the bridge deck. For that reason, the measurement of the elevation on crossings with interchange roads is severely unreliable.

As described in the methodology, the longitudinal gradient from the cartographic plan was obtained applying the equation (1). As an example, the gradient calculation of the segment i_4 using the topographic profile of Av. *Papa João Paulo II* is presented in Fig. 6. The endpoints of i_4 are p_4, with an elevation y_4 equal to 178m and abscissa x_4 equal to 231.10m and p_5 with an elevation y_5 equal to 183.20m and abscissa x_5 equal to 382.76m. With these values, the calculation of the gradient percent is done as follow:

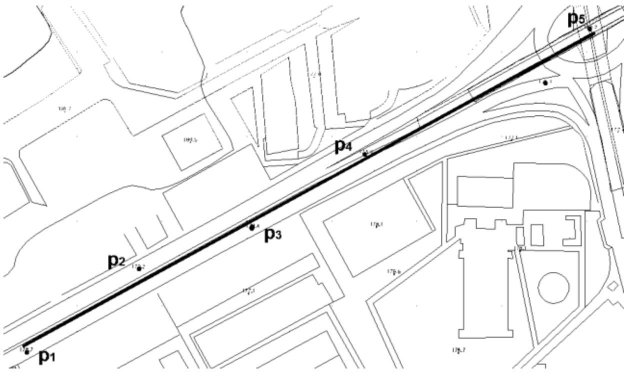
$$i_4(\%) = \frac{183.20 - 178.00}{382.76 - 231.10} = 3.4$$

Fig. 6 - Street profile of Av. *João Paulo II* (no scale)



As it can be seen in Fig. 7, this segment represents an ascending ramp due to an overpass at the intersection of Av. *Papa João Paulo II* and the Av. *Frei Bartolomeu dos Mártires*.

Fig. 7 - Topographic extract of the *Av. João Paulo II* (no scale)



In order to collect comparable values to evaluate the reliability of the "low-cost" tools (digital inclinometer - DMN 120 L and hand held Laser Distance Meter - DISTO D8), the same Avenues of the city of Braga were evaluated. Gradients were measured using both tools and, at the end, the values were compared with those collected using cartographic data, to finally evaluate the accuracy and reliability of the tools, considering as the most trustable value those collected from cartography.

For both devices (tools), gradients were measured on sidewalks, parallel to roadway and using a regular distance between measurement points (to evaluate each stretch), which in this case, was an approximate distance of 50 meters.

Fig. 8 shows the longitudinal change in road gradient obtained for each road stretch (segment) through all four tools (cartography, Google Earth, DMN 120 L and DISTO D8).

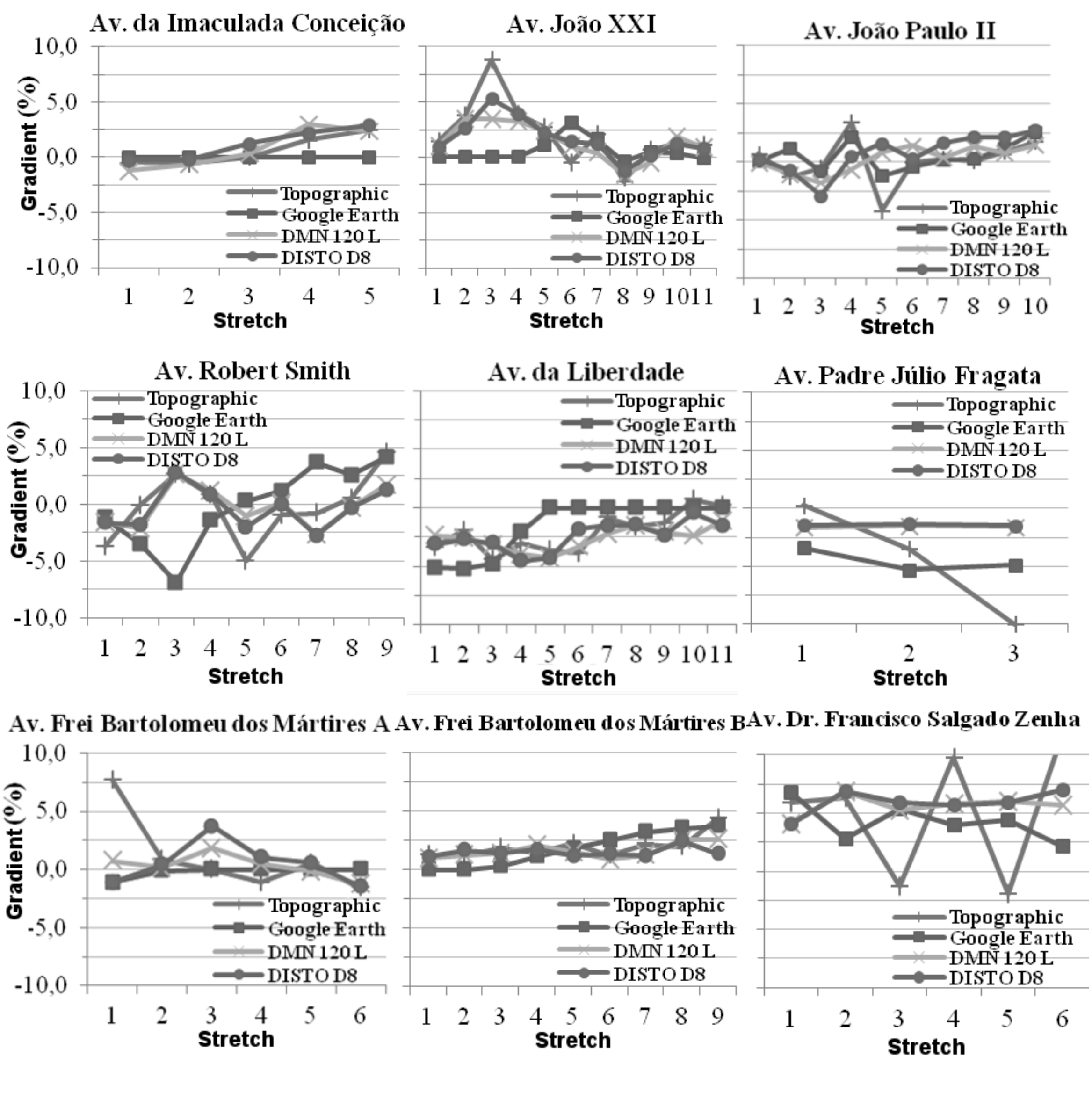
The segments were defined using points in which elevation was determined through cartography, following the evaluation and calculation of the gradient by the other tools.

In Table 6 and Fig. 8 are presented the results of the average gradient of the nine selected Avenues due to the calculation of the weighted average of the segments by theirs lengths and a comparison was made by the data gathered on cartographic plans and the other tools.

With data collection concluded, it was possible to generate the gradient profiles for each Avenue, defining the initial elevation as equal to the initial elevation measured in cartographic plans. Then, the calculation of an average gradient was obtained, weighted by the length of the defined segments.

With the obtained data, the graphs of Fig. 8 were

Fig. 8 - Average gradients of road segments



generated. The correlation between gradient values obtained using the existing cartography and those gathered with Google Earth, was then calculated and the result was 0.94, which represents a very strong correlation. The correlation between data obtained using cartographic data and the digital inclinometer DMN 120L was calculated and the result was 0.97 (very strong correlation). The same calculation was made for the Distance Meter DISTO D8, getting a result of 0.96 (very strong correlation).

Table 6 and Fig. 9 present the average inclinations values obtained for each Avenue.

Table 6 - Average gradient of the avenues (%)

Location (Avenues)	**i_i (%) Cart.**	**i_i (%) Google Earth**	**i_i (%) DMN 120 L**	**i_i (%) DISTO D8**
Av. *da Imaculada Conceição*	0.6	0.0	0.8	1.08
Av. *João XXI*	2.1	0.6	0.9	1.26
Av. *João Paulo II*	0.1	0.5	0.3	1.06
Av. Robert Smith	-0.2	-0.1	-0.1	-0.26
Av. *da Liberdade*	-2.1	-1.6	-2.9	-2.83
Av. *Padre Júlio Fragata*	-4.4	-4.5	-1.5	-1.41
Av. *Frei Bartolomeu dos Mártires A*	1.0	-0.2	-0.1	0.49
Av. Frei Bartolomeu dos Mártires B	2.0	1.8	1.8	1.58
Av. Dr. Francisco Salgado Zenha	5.1	4.3	5.5	5.58

6 Statistical analyses of the results

In this section a comparison between the mean values of the gradients obtained for the four tools to verify the statistical level of significance of the results, using T-tests.

In Table 7, 9 and 11are presented a group of descriptive statistics for each tool with the mean values, the Standard deviation of the sample and the mean and the number of observations – N (gradient of stretches). Since the N (070) is higher than 30 the T-Test can be applied because it can be assumed that this is a big sample and Central Limit Theorem can be applied and it can be assumed that the sample distribution is approximately Normal.

In Tables 8, 10 and 12 are presented the results for T-Test for independent samples. A comparison of means among the cartography values and the three different tools was accomplished. It must be enhanced that the main issue is that comparison is only with the most reliable source. Otherwise, if the objective was to obtain a comparison between all tools at the same time T-Test error would increase and ANOVA Test should be performed.

Taking into account the 2 first columns of Tables 8, 10 and 12 of the Levene's Test for Equality of Variances it is possible to observe that the Z-Test has a p-value (Sig.) > 0.05 then the null hypothesis cannot be rejected by which it can be assumed equal variances.

Fig. 9 - Average gradients: Cartography, Google Earth, Digital Inclinometer and Laser Distance Measurer

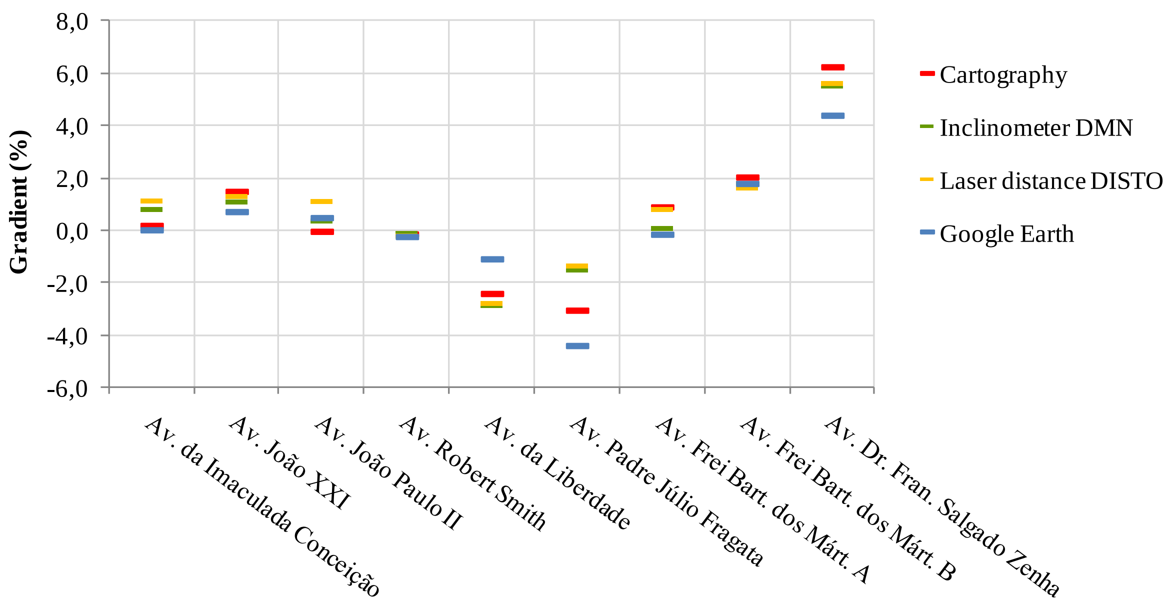


Table 7 - Group Statistics: Cartography vs Google Earth

	ID_Equipment	N	Mean	Std. Deviation	Std. Error Mean
Gradient (%)	g_Cart.	70	0.62218	3.453916	.412822
	g_Google	70	0.29143	2.534215	.302897

Table 8 – Independent Samples between cartographic and Google Earth data

		Levene's Test for Equality of Variances		teste-t for equality of means						
									95% Confidence Interval of the Difference	
		Z	Sig.	t	df	Sig. (2-tailled)	Mean Difference	Std. Error Difference	Lower	Upper
Gradient (%)	Equal variances assumed	3.566	**0.061**	0.646	138	**0.519**	0.330754	0.512024	-.681673	1.343180
	Equal variances not assumed			0.646	126.599	0.519	0.330754	0.512024	-.682480	1.343987

Table 9 - Group Statistics: Cartography vs Laser Distance Meter DISTO

	ID_Equipment	N	Mean	Std. Deviation	Std. Error Mean
Gradient (%)	g_Cart.	70	0.62218	3.453916	0.412822
	g_DIST	70	0.71064	2.534483	0.302929

Table 10 – Independent Samples Test: Cartography vs Laser Distance Meter DISTO

		Levene's Test for Equality of Variances		teste-t for equality of means						
									95% Confidence Interval of the Difference	
		Z	Sig.	t	df	Sig. (2-tailled)	Mean Difference	Std. Error Difference	Lower	Upper
Gradient (%)	Equal variances assumed	1.621	.205	-0.173	138	.863	-0.088460	0.512043	-1.100924	0.924004
	Equal variances not assumed			-0.173	126.606	.863	-0.088460	0.512043	-1.101730	0.924811

Table 11 - Group Statistics: Cartography vs Digital inclinometer DMN

	ID_Equipment	N	Mean	Std. Deviation	Std. Error Mean
Gradient (%)	g_Cart.	70	0.62218	3.453916	0.412822
	g_DMN	70	0.51923	2.417734	0.288974

Table 12 – Independent Samples Test: Cartography vs Laser Distance Meter DISTO

		Levene's Test for Equality of Variances		teste-t for equality of means						
									95% Confidence Interval of the Difference	
		Z	Sig.	t	df	Sig. (2-tailled)	Mean Difference	Std. Error Difference	Lower	Upper
Gradient (%)	Equal variances assumed	2.177	.142	.204	138	.838	.102954	.503913	-.893435	1.099343
	Equal variances not assumed			.204	123.528	.838	.102954	.503913	-.894468	1.100376

On the other hand, T-Test for mean comparisons has shown a p-value (Sig. (2-tailled)) higher than 0.05 the null hypothesis cannot be rejected and the mean among the cartography and the other three tools cannot be considered different with statistically significance. Indeed the mean values are very similar, thus it can be conclude that the three tools can be used to evaluate the gradient of cycle paths.

The non parametric test of independence of Chi-Square was used to test if two variables in population are independent. Chi-Square also allow to test if two or more independent samples (or groups) differ in relation to a specific characteristic, i.e. if the frequency as the elements of the sample are distributed by the classes by which a variable is categorized. The null hypothesis H0: There are no differences among the samples in relation to distribution in the classes of a variable, or equivalently H0: the counting distribution by the groups is independent of the variable.

In this study the purpose of this test is to know if the distribution in the classes (number of cases) of the gradient for cycling defined in Table 1 is independent of the tools used to evaluate the gradient, i.e. the variables are not related.

In the Table 13 are registered the counts and the expected counts as well the distribution of the number of cases per classes of gradient for cycling. As it can be seen the proportions are similar as it was expected due to the methodology applied in this work. Finally, Table 14 presents the statistics for Pearson Chi-Square Test and the probability of significance associated (Asymp. Sig. (2-sided) and Exact Sig. (2-sided)). Since the p-value = 0.039 < 0.05 then the null hypothesis must be rejected and the alternative hypothesis accepted, so the variables are related and distribution of the number of cases by the classes for the four tools vary according the used tool. On the other hand, the last table indicates that the "4 cells (25.0%) have expected count less than 5. The minimum expected count is 1.00." In this situation the Chi-Square is not rigorous, since the number cells with a expected count less than 5 must be lower than 20% of cells.

Thus it should be concluded that the use of low-cost tools is not rigorous and should be carefully applied in the planning process.

Table 13 – Gradient classes for cycling * tools (ID_Equipment) Crosstabulations

			ID_Equipment				
			g_DIST	g_DMN	g_Cart.	g_Google	Total
Gradients (%)	0 - 3%	Count	58	56	49	52	215
		Expected Count	53.8	53.8	53.8	53.8	215.0
		% within ID_Equipment	82.9%	80.0%	70.0%	74.3%	76.8%
	3 - 5%	Count	6	9	14	12	41
		Expected Count	10.3	10.3	10.3	10.3	41.0
		% within ID_Equipment	8.6%	12.9%	20.0%	17.1%	14.6%
	5 - 8%	Count	6	5	3	6	20
		Expected Count	5.0	5.0	5.0	5.0	20.0
		% within ID_Equipment	8.6%	7.1%	4.3%	8.6%	7.1%
	>8%	Count	0	0	4	0	4
		Expected Count	1.0	1.0	1.0	1.0	4.0
		% within ID_Equipment	0.0%	0.0%	5.7%	0.0%	1.4%
Total		Count	70	70	70	70	280
		Expected Count	70.0	70.0	70.0	70.0	280.0
		% within ID_Equipment	100.0%	100.0%	100.0%	100.0%	100.0%

Table 14 – Chi Square Tests for Gradient classes for cycling *vs* tools (ID_Equipment)

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi- Square	**17.692[a]**	**9**	**.039**	**.033**		
Likelihood Ratio	17.058	9	.048	.063		
Fisher's Exact Test	12.786			.117		
Linear-by-Linear Association	1.519[b]	1	.218	.234	.117	.015
N of Valid Cases	280					

a. 4 cells (25.0%) have expected count less than 5. The minimum expected count is 1.00.

b. The standardized statistic is 1.232.

7 Conclusions

In this section, the main conclusions of the study about assessing the reliability of the application of some tools, considered as "low-cost" tools, to measure the gradient of terrains and road infrastructures in the city of Braga, Portugal, are presented:

i. The use of Google Earth software for measuring gradient of some private or public inaccessible spaces, for instance Universities campi, is not reliable due to lack of available data provided by the software;

ii. For a preliminary assessment of the geomorphologic suitability of some streets segments, e.g. segments or stretches of Avenues, the tools were not reliable. There was a reasonable correlation between data obtained by the Digital Inclinometer and Laser Distance Measurer tools and data from the cartography, but a low correlation between the Google Earth measurements and data from the cartography;

iii. For a preliminary assessment of the geomorphologic suitability of the entire extension of streets, the tools presented good levels of reliability. A strong correlation between the values obtained and data from the cartography was obtained: the digital inclinometer DMN 120L came up as the most reliable tool, followed by the laser distance measure DISTO D8 and then by Google Earth;

iv. Measuring gradients using any of the tools presented in this paper is unreliable, since it will be possible to get a substantial error for small segments. Since the gradient is a relation between distance and the variations of elevation, any small error in the measured extension can cause a major error in the final value of gradient. However, when leading with long segments, small differences in measured distances will result in almost imperceptible differences in the final value of gradient;

v. Taking as reference collected data with the Digital Inclinometer and the Laser Distance Measure, all Avenues evaluated, except two, would be classified as excellent for cycling. The exceptions, Av. Padre Júlio Fragata and Av. Dr. Francisco Salgado Zenha, would just be classified as satisfactory, requiring the appliance of resting zones for cyclists, or an additional width to ensure that slow cyclists can travel safely;

vi. Taking collected data with the Digital Inclinometer and the Laser Distance Measure as reference, all Avenues evaluated, except one, would be classified as excellent for cycling. The exception, Av. Dr. Francisco Salgado Zenha, would just be classified as satisfactory, requiring measures to help cyclists in ascending direction.

vii. Google Earth, DMN 120 L and DISTO D8 can be used to conduct a preliminary assessment of the geomorphologic suitability of a terrain to receive a cycle lane or track in stretches with a reasonable extent. However, it is important to enhance that, for design phase of a cycling route, it is necessary to gather data using a more reliable tool than the "low-cost" tools previously described and tested.

These tools can also be used to audit the urban road environment for pedestrians and cyclists, especially the evaluation of walkability and bikeability of streets in order to enhance the use of active modes of transport for commuting purposes in our cities according to Galanis and Eliou [28] and Eliou et al. [29] but also to promote sustainable mobility of urban areas [30].

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