Integrated Modeling of Road Environments for Driving Simulation

Carlos Campos[1,2], João Miguel Leitão[1] and António Fernando Coelho[2]
[1]*Department of Electrical Engineering, School of Engineering of Porto Polytechnic, Porto, Portugal*
[2]*Department of Informatics Engineering, Engineering Faculty of Porto University, Porto, Portugal*
{crc, jml}@isep.ipp.pt, acoelho@fe.up.pt

Keywords: Procedural Modelling, Road Network, Road Layout, Road Design, Driving Simulation.

Abstract: Virtual environments for driving simulations aimed to scientific purposes require three-dimensional road models that must obey to detailed standards of specification and realism. The creation of road models with this level of quality requires previous definition of the road networks and the road paths. Each road path is usually obtained through the dedicated work of roadway design specialists, resulting in a long time consuming process. The driving simulation for scientific purposes also requires a semantic description of all elements within the environment in order to provide the parameterization of actors during the simulation and the production of simulation reports. This paper presents a methodology to automatically generate road environments suitable to the implementation of driving simulation experiences. This methodology integrates every required step for modelling road environments, from the determination of interchanges nodes to the generation of the geometric and the semantic models. The human supervisor can interact with the model generation process at any stage, in order to meet every specific requirement of the experimental work. The proposed methodology reduces workload involved in the initial specification of the road network and significantly reduces the use of specialists for preparing the road paths of all roadways. The generated semantic description allows procedural placing of actors in the simulated environment. The models are suitable for conducting scientific work in a driving simulator.

1 INTRODUCTION

Procedural modelling of realistic road environments is a research area of great interest, which is dedicated to generating 3D models, not only for entertainment but also for scientific applications. This paper presents the current implementation state of a methodology for the automatic creation of road environments for driving simulation for scientific purposes.

Driving simulators are an important research tool in several scientific areas, such as psychology, ergonomics and roadway engineering.

In psychology, they are used to develop researches related with the driver behaviour. For example, evaluate the interference of secondary tasks in principal driving task, like mobile phones, navigation systems or traffic information systems.

The driving simulators are also used in ergonomics area to study "In Vehicle Information System", of interaction with the driver, like navigation systems (GPS) or mobile phones.

In roadways engineering, they are used to analyses road paths in design stage, but also real roads, allowing the test with real drivers, for example the study of factors that conducts to dangerous driving.

In traffic engineering also allow the study of dangerous overtaking maneuver with frontal collision probability in roads with two lanes, one in each direction, without compromise the driver safety.

Driving simulation experiments require the creation of extensive road environments with specific technical features, such as the placement of actors and the production of detailed reports. In order to place the actors in the simulated environment and produce the reports, a semantic description of the entire generated environment is also required.

Road environments for driving simulation usually consist of road networks. The strategic design of a road network involves the previous definition of nodes (cities, intersections, roundabouts, etc.) that will be interconnected and the type of road to implement.

This definition often involves very different disciplines, in addition to the roadways design, and requires an analysis of the network as a whole.

This process produces the topological definition of the roads network, that specifies the connection between nodes and the related typologies of roadway (highway, secondary roads and rural). The highways connect cities, secondary roads connect cities with small towns, and rural roads connect small towns with villages.

The creation of this road network definition can become a too hard-working and resource consuming task, if done by specialists applying traditional roadway design methods. These difficulties cannot be completely solved by the use of any of the available dedicated tools, like the Autodesk Civil3D. The road path definition is very important to the realism of the road environment. The road path should have geometric characteristics like those found in the real world.

After obtaining the road path, it is still necessary to generate the visual model. One way to optimize this process is to use automatic modelling tools to facilitate this task, like the ones presented in (Campos, 2007).

Additionally, besides generating the model of the network and the related road paths, it is still necessary to edit the terrain model surrounding each road path that makes up the roads network, to produce models that meet the required visual quality.

For driving simulation experiments, the required high fidelity visual models must also be completed with the corresponding semantic description of the entire virtual environment, as also pointed out in (Thomas, 2000).

The semantic definition is a high-level description and characterization of the road environment, which allows parameterizing the dynamic model of the virtual environment. This description is fundamental in simulation systems for placing actors (e.g. pedestrians, other vehicles), monitoring the entire simulation and report generation. The availability of this reports and the details included are very important in scientific driving simulation experiments. These reports are essential for further analysis and data processing relating to experimental test. Traditional modelling tools for virtual environments do not allow the joint creation of these two representations, semantic and visual.

To allow the generation of fully controllable environments, the preparer of the experiment must be able to interact with the generation process, by imposing specific requirements for each element. This feature is critical in the generation of virtual environments for driving simulation for scientific purposes.

In this paper, section 2 presents the state of art in the generation of road environments and the relevant related work. The proposed methodology is presented in section 3, and in section 4 we present the results obtained with the implemented prototype. Section 5 presents the conclusions and proposes some guidelines for future work.

2 STATE OF ART

2.1 Roads Design

As described in (Campos, 2012), a road network can be defined by a set of nodes and links that connect them. Each road is planned to connect two or more points of interest, allowing the movement of vehicles between them. Planning a road network aims to satisfy the needs of people, seeking to meet the standards of service levels. A road network can be defined by a hierarchical structure of connections in 3 levels: the highway network, the secondary road network and rural road network (Teoh, 2008) (Weber, 2009).

The design of a road starts with a strategic decision to connect two points on the existing roads network. Essentially, this decision is made by taking into account parameters such as population growth, level of service, traffic studies and estimated construction cost.

In roadway engineering, a project of a road path is developed according to the following phases: preliminary program, prior study and project of implementation (França, 2011). The preliminary program is basically a specification consisting of general rules, with little detail, which include the general characteristics desired and that may condition the choice of road path.

The preliminary study is not intended to provide definitive elements, nor the detail required for the road works. The main objective is to point out one or several alternative solutions for tracing the road path. This stage involves traffic studies, geological and geotechnical studies, landscape and environmental impact studies. The results of these studies will restrict the road path of the roadway, but leaving some degrees of freedom to a further decision. When the previous study is concluded and approved, the project of road path begins. The route is now defined with necessary detail to its implementation in the real world. The definition of the horizontal alignments of the road is the first task to be performed in this step, followed by the remaining specialities.

In order to produce the horizontal alignments, one begins by specifying the centreline, with the introduction of horizontal curves. It follows the vertical alignment (altimetry), where vertical curves are defined. Lastly, the road cross-section specified. The road path definition must conform to the rules established by the applicable standards design. In Portugal, these standards are defined by Estradas de Portugal, which is responsible for maintaining the road network (EP, 1994).

2.2 Related Work

Several works have been developed for creating road city environments, focusing mainly on urban layout (Parish, 2001)(Chen, 2008)(Teoh, 2008)(Coelho, 2007)(Vanegas, 2010).

Typically, the produced networks of urban roads follow a certain predefined pattern: orthogonal, radial or branching (Sun, 2002). The results obtained by these methods are usable for most visual simulation applications. The problem with these approaches is the need for an excessive control by the user to obtain realistic models. Also, the use of a pre-defined pattern for the road network is not adequate when specific road layouts are required. Besides, these methods don't produce extra-urban roads network.

Procedural modelling languages, e.g. L-systems and CGA shapes, are not adequate to produce extensive road paths for driving simulation (Paris, 2001)(Muller, 2006)(Coelho, 2007). Is known that the driver easily learn the road layout in an experimental work, therefore repetition of road segments is not advisable. The expectation component of the road path is a very important variable in a driver behaviour research.

Driving simulation experiments typically require mixed road environments, with roads models of good quality, with realistic road paths, combining roads from urban and rural environments.

A proposal for the procedural modelling of virtual environments suitable for real-time simulation is presented by Smelik et al. in 2008 (Smelik, 2008). The authors describe a process in which the virtual environment is created hierarchically from an initial sketch, including treatment of the road network. A benefit of this hierarchy is that each layer can be treated individually and the final model generation process takes into account the appropriateness of all settings, including the terrain model, as discussed in (Latham, 2006). In the proposal presented by Smelik et al., it isn't clear what methodology was used to generate the road path. In a further publication in 2001, Smelik et al. present a modelling approach of a virtual environment, using an interactive modeller (Smelik, 2011). The generation of the virtual environment requires an excessive control by the user so that the process ceases to be fully automatic. For the generation of geometric models of roads, some procedural modelling techniques of urban networks presented by Kelly et al. in 2008 are explored (Kelly, 2008).

Galin et al. present a methodology for procedural generation of roads paths, where the generation of the road path is done using a complex algorithm, on a terrain defined as a digital elevation map (Galin, 2010). At each step of the process the direction to follow is determined by the local evaluation of the cost of each alternative. This use of a local assessment prevents a proper evaluation and global optimization of the final solution. Depending on the terrain model and the typologies of the road, the option for a maximum number of alternatives to be study may be too complex. The presented description does not allow to concluding if the proposed method produces road layouts similar to those found in real road paths. The realism evaluation of the obtained models is also not presented. During the generation of the visual model, all 3D models, such as bridges, tunnels and road crossings are instantiated.

A methodology for generating a road network that integrates different typologies of roads (highways, main roads and secondary roads) is presented by Galin et al. in (Galin, 2011). The generation of the global transport network is initiated by the creation of the motorway network, followed by the main network and the secondary network last. Each type of roads is created independently. At the end, all the roads are overlapped in a single road network. The way this problem is handled, requires that the design of roads has to be recalculated.

Thomas et al. showed a model implementation of a virtual city where several actors (like pedestrians, vehicles and public transport vehicles driven by other drivers circulating in different directions) are included and controlled over the complex urban road environment (Thomas, 2000). The urban environment was created using the interactive modeller VUEMS and based on a terrain definition in a digital elevation map (Donikian, 1997). The use of an interactive modeller is not suitable for the generation of extensive road environments automatically and efficiently.

In the work presented by Bayarri et al., methodologies for the generation of road environments appropriate for driving simulation from design data are described (Bayarri, 1996)(Pareja, 1999). Each time you want to get a model of a roadway, it requires prior interaction with the area of engineering of roadways, or other sources, for the delineation of the road paths. Some of these methodologies have been explored in previous works (Campos, 2007).

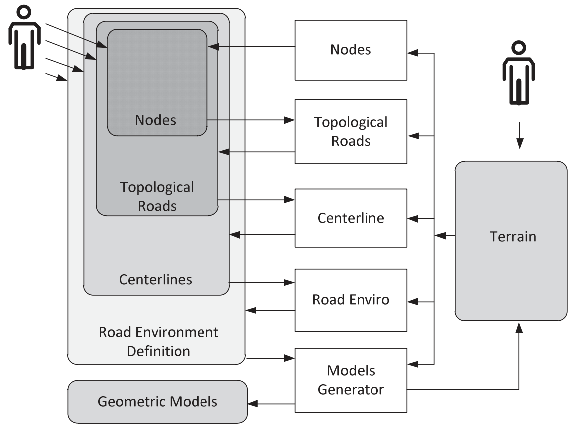
In order to implement experiments in driving simulation, beyond the generation of road layout and modelling of virtual environments, the corresponding semantic definition should also be created. As mentioned in (Thomas, 2000), the semantic definition is a description of the characterization of high-level road environment, which supports the dynamic model of the virtual environment. The creation of a semantic description in accordance with the road map is also addressed in other works (Campos, 2007)(Bayarri, 1996)(Pareja, 1999).

The OpenDrive Project has developed a standard for the complete description of a road network to be compatible with various simulation systems (OpenDrive, 2010). It is stated that the proposed standard allows the parameterization of the main features of real roads. An interactive modeller that uses this standard is the Road Designer (ROD, 2011).

Creating models of realistic roads for driving simulation is usually performed by manual, laborious and slow processes, even when the available interactive tools are applied. Whenever a realistic road environment to driving simulation experiments is needed, a high level of interaction with the preparer is usually necessary, which requires experts in road design. An alternative to this problem is to develop a methodology for automatic generation of road environments, from the definition of nodes, topological definition of the network, generation of road paths and semantic description until the generation of the visual model.

3 INTEGRATED MODELING OF ROAD ENVIRONMENTS

The proposed methodology creates, in an integrated way, a complete road environment from the generation of inter-changes nodes to the construction of the three-dimensional model. The process of generating the three dimensional model is organized hierarchically in layers, which also gives a semantic description of the road environment, as illustrated in figure 1.



Thus, highways connect cities, secondary roads connect cities and towns, and rural roads connect towns and villages. Additional nodes of inter-connection may be created, with an importance factor of zero.

The Centerline module is responsible for generating the definition of road paths for each roadway in the network. This module receives the definition of the topological road network generated by the Topological Roads module. For each connection, a definition of the road path is created. The methodology of generating a road path was inspired by the methods used in roadways engineering, producing models that meet the design standards and with geometric characteristics similar to those found in real world.

The suitability of the terrain model to the generated road network is performed by Road Enviro module. This module receives the definition of the road paths of all the roadways generated by the Centerline module and fits the terrain model to the respective geometric definition of each roadway.

The Models Generator module is responsible for procedurally generating the geometric model of the roadways, where the previously studied techniques are explored (Campos, 2007). This module is also responsible for generating the geometric model of the terrain.

In the hierarchical process of generating a road environment, the preparer of the model can interact at any stage of the process, modifying the result produced by any module and creating a custom layout. For example, the preparer can add new nodes, edit or delete a connection, redefine a road path or edit the definition of the terrain.

This freedom of interaction with the model at any stage of the generation process is a special contribution of this methodology that enables producing fully customized models, allowing fulfil of any particular specification required for the experimental work.

At the end of the generation process, the semantic description is also made available, which allows the parameterization and placement of actors in the simulated environment, e.g. other vehicles, pedestrians or any other moving element. This facility is crucial for implementing driving simulation experiments aimed to scientific purposes.

3.1 Nodes and Topologic Roads Network

The proposed methodology to create a topological road network requires the previous definition of the interchange nodes set. If there is no previous definition of these nodes, the Nodes module is able to automatically generate a simplified definition of nodes on an area of terrain, in which each node is associated with an importance factor. The importance factor can match the population and is used to organize the nodes by typology. The nodes are organized into three typologies: city, town ad village. Once the definition of nodes is available, different topological roads networks are created: highways, secondary and rural.

The process starts from nodes of city typology, creating a network of highways. All possible connections linking a pair of cities are analysed and the benefit of its existence is evaluated. During the review process, the decision to remove a connection depends on the difference between the cost of road construction and the benefit of keeping that connection. The benefit is related to the utilization index (U), which depends on the total length of the roadway (L) and the population resident in each of the ends nodes, PA and PB (1).

$$U = PA * PB / L^2 \qquad (1)$$

The benefit (B) is determined according to the utilization index U, the difference between the road connection length and the shortest alternative route, and the unitary cost of operation (Cop), which measures the traveling cost of vehicle per kilometre (2).

$$B = U * (L_{connection} - L_{shortest}) * C_{op} \qquad (2)$$

If an edge connection of the graph is removed, the cost of this decision makes the movement between the ends nodes may be longer, what don't match a particular problem.

After simplifying the roads network, there can be many intersections between two road paths. In this case, additional interconnection nodes are generated. These nodes have an associated importance factor (population) of zero. Interconnection nodes with zero population appear as gray nodes in figure 2.

In order to generate the secondary road network, the nodes with village typology are added to the highways network obtained in the previous process. All possible connections between villages and towns are then analysed, using the same procedure applied to the highway network.

The process of generating the topological roads networks may be parameterized in order to obtain a representation of highways, adequate and similar to a real roads network. At the end of the process, we obtain a definition of the network of connections, between two nodes, as shown in figure 2.

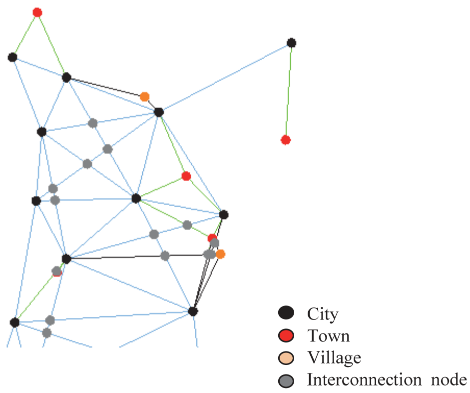


Figure 2: Topological roads network.

After obtaining the definition of the topological roads network, a road path is generated for each roadway.

3.2 Road Paths

As described in (Campos, 2014), the selection of a road path (T) connecting two given nodes (a and b), can be explained by an optimum search function aimed to minimize a cost function that evaluates the influence of different indicators, such as the relationship with the terrain definition and the constraints.

The proposed procedure for generating a road path is hierarchically organized in layers. Starting from the definition of a connection between two nodes, a set of high level solutions with little detail is first generated in the first layer. At each layer, new road layout definitions with growing levels of detail are generated.

At each layer, several alternatives road paths are generated. The choice of the best hypothesis at each layer is performed by a cost function that evaluates several parameters, such as terrain affection and the related constraints.

The strategy of generating a road path according to a specific level of detail mimics the method usually applied by civil engineers when designing road path of real roadways. This straight connection to real design processes eases the selection of every required parameter and grants that the produced output will be similar to a real road path. Once the road path is defined in straight alignments with the required level of detail, the horizontal alignments and the altimetry layout are developed. Horizontal alignments are achieved with the introduction of horizontal curves and the development of the in with the introduction of vertical curves. A horizontal curve consists in an input clothoid, a circular arc and an output clothoid.

The produced definition of the road path includes information about every road segment and its construction class as normal road, bridge or tunnel. The costs considered in the evaluation of a road path are: classified area, bridge construction, tunnel construction, earthwork, roadway construction and cost of use. A classified zone is defined as a geographical area in blueprint that represents a particular constraint, such as water, forest or buildings.

To determine the impact of a road path on a classified zone it is necessary to calculate the area of the zone affected by the road crossing. To determine whether a portion of the length of the roadway is built as a bridge or tunnel, an analysis of the difference between the elevation of the terrain and elevation of the roadway is made. It's also considered the bridge construction where the roadway crosses water, for example, a river or a lake.

To evaluate the moved ground volume it is necessary to analyse the difference between elevations of the terrain and the road. The reference values for the costs analysed in the study of alternative alignments were determined using specialists in roadways design, and are discussed in (Campos, 2014).

3.3 Road Environment

The construction of roadways in real world implies earthworks in the terrain where the road is implemented. A slope is the terrain surface which is located along the road and can be originated by natural or artificial causes. Artificial slopes are created during construction of roads and are a result of excavation or embankment on the terrain. They are aimed to ensure the stability of the natural terrain. The declivity of cut slopes and embankment slopes are defined according to geological and geotechnical studies. Generally, the cut slope and embankment slopes have declivity of 1 to 1.5 (V/H) so that the stability of the ground is guaranteed (EP, 1994).

In the proposed methodology, after generating the trajectory of the road, it is necessary to adjust the definition of the terrain to generate the visual model without failures. These changes to the altimetry of the terrain model typically result in cut and embankment slopes.

An efficient way to realize the change in the altimetry of the terrain consists in, for each point of the terrain, checking if the altimetry value is influenced by the presence of the road. For each point of the terrain, the minimum distance to the road is calculated and, according to this distance, the need to change the z coordinate of the point of terrain evaluated. This process may result in the cut or embankment slopes, as shown in figure 3.

The z coordinate of the point of the terrain is not altered if it is positioned between the definitions of slopes, as illustrated in figure 3, for the point P3.

We can also see in figure 3 that point P1 is shifted to P'1 point, and the point P2 is shifted to P'2 point.

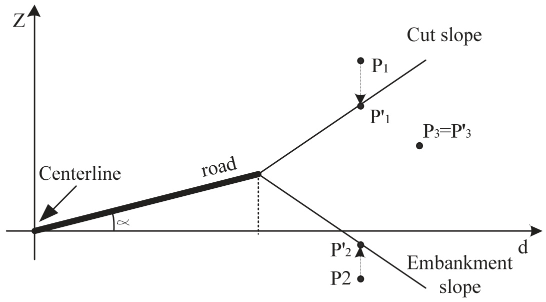


Figure 3: Cut and embankment slope.

In order to optimize this process, the terrain points that are relatively far are not treated. In the edition of the terrain, the modelling information of the edited areas is registered so that, it is possible to provide these areas with a different color (typically brown) during its visualization.

The horizontal signalization is made by road marks, defining the lanes in each road segment. These marks may have different layouts: continuous, discontinuous or both. In order to improve the visibility detection, horizontal signalization models are hierarchically organized with the road models using different layers. The vertical signalization is placed in road environment by instantiating 3D objects.

In this way the road environment is procedural modelled, producing 3D models that meet the detailed standards of specification and required visual quality.

3.4 Semantic Model

During the creation of a road environment, a semantic description of the entire model is generated. This description is fundamental in driving simulators aimed to scientific purposes, not only for the production of reports, but also for the parameterisation of actors and traffic events. The inclusion of actors and the parameterisation of traffic events make the driving experience more realistic and immersive.

In driving simulation, typically road environments are enriched with the placement of actors, such as other vehicles and pedestrians. In driving simulation experiments where the objective is to study the behaviour of the drivers, the placement of other vehicles and specification of precise traffic events is normally required.

In order to place actors and allow the specification of traffic events, some other levels of information beyond the definition from the centerline must also coexist. These include data such as the roadway width, the width of the road sides, the number of lanes, the width of each lane and the road signs.

4 RESULTS

The results presented in section 3.1 were obtained by the prototype implemented applying the methodology described in this paper. To demonstrate the quality of the results obtained by this methodology and provide a critical analysis, the following case study was prepared:
The aim of this implementation was to get the road environment corresponding to two typologies of roads (rural and highway) for a connection without nodes, between two cities (Porto and Braga) of the topological road definition generated, presented in section 3.1.

The population of Porto is 273 584 inhabitants and a population of Braga is 93587 inhabitants. Population was used as an approximation for the importance factor.

The rural road was designed for a base speed of 60 km/h with two lanes, one in each direction, corresponding to a total reference width of 12m. The highway was designed for a base speed of 120 km/h, with two carriageways, one in each direction, with two lanes each, corresponding to a total reference width of 40m.

The model of the real terrain was obtained from a digital elevation map in GEOTTIF format, from the United States Geological Survey repository (USGS, 2014). The constraints due to water and forest were set to a geographical area affected by the road layout. In this implementation, the areas that represent constraints were defined in an image file in the TIFF format (Libtiff, 2014).

The applied methodology produces several definitions of the road path, with an increasing level of detail. The image in figure 4 shows the road path generated in straight alignments (black) and the horizontal alignments, resulting after the introduction of horizontal curves (blue).

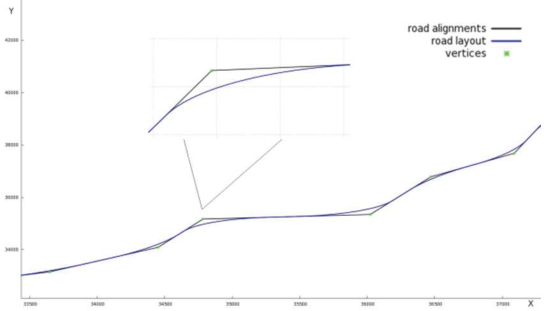


Figure 4: Design of road path.

In figure 5, we present the produced road layout in a 3D view.

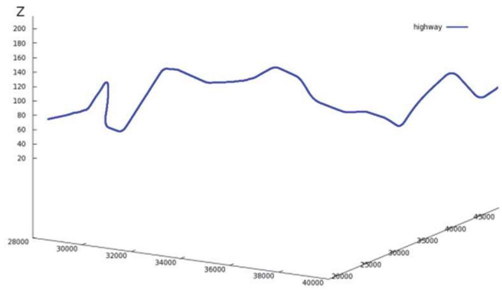


Figure 5: Road layout in a 3D view.

It is expected that the road path of a highway is less winding when compared to a road path designed for a lower base speed, in order to provide greater comfort to the driver. Typically, the sinuosity of horizontal alignments on highways is smaller than the sinuosity on a rural road. This feature is also observed in the altimetry layout. One way to analyse the sinuosity of the horizontal alignment is to use the discrete Fourier transform and perform an analysis on the curvature domain. By comparing the results obtained in the curvature domain of procedurally generated models to real road paths, allows concluding that the road paths generated by the proposed methodology are similar to those found in real world, like has discussed in (Campos, 2014).

Using the obtained road layout, the terrain model is modified, in order to generate the corrected visual model. This terrain correction is performed by a specially developed module.

In figure 6, we present a rural roadway environment, designed for a base speed of 60 km/h.

In the figure 7, we present the road environment of highway, designed for a base velocity of 120 km/h.

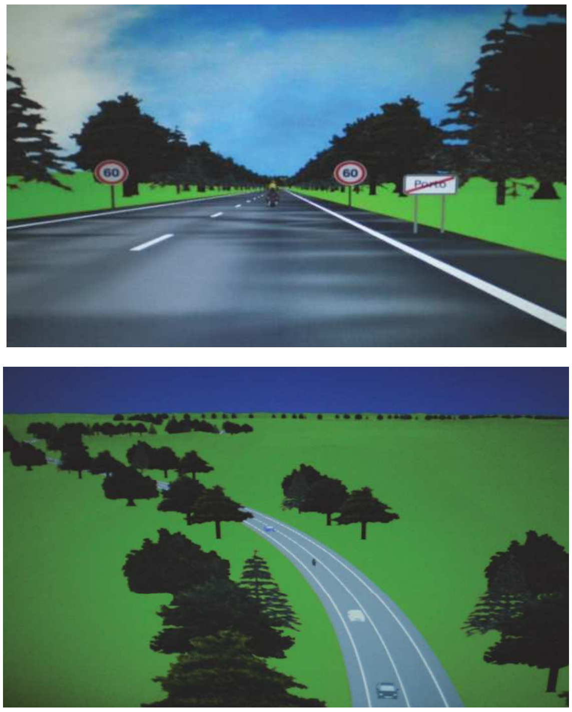


Figure 6: Rural road environment.

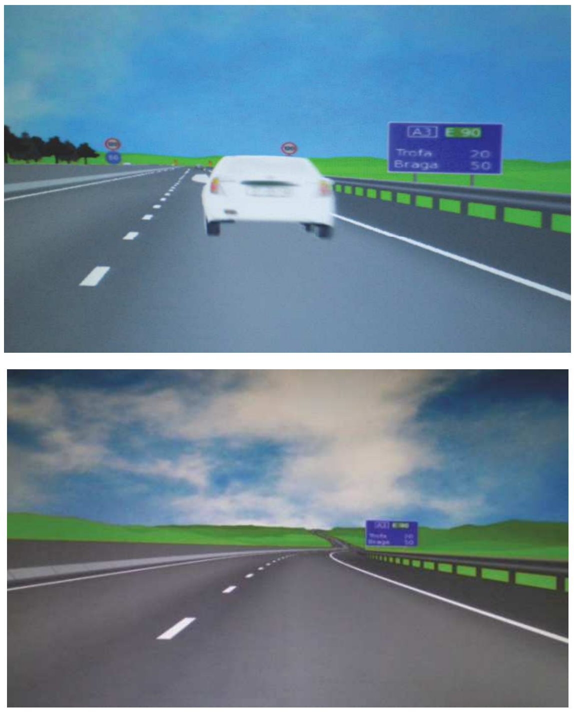


Figure 7: Highway road environments.

The inclusion of others vehicles can be placed in the simulated environment, in a procedural way. As we can see in figure 6, 7 and 8, others vehicle are procedural placed in the road environment.

In figure 8, we show the resulting visual model with a perfect fit between the generated road and the surrounding terrain, where we can see cut and embankment slopes.

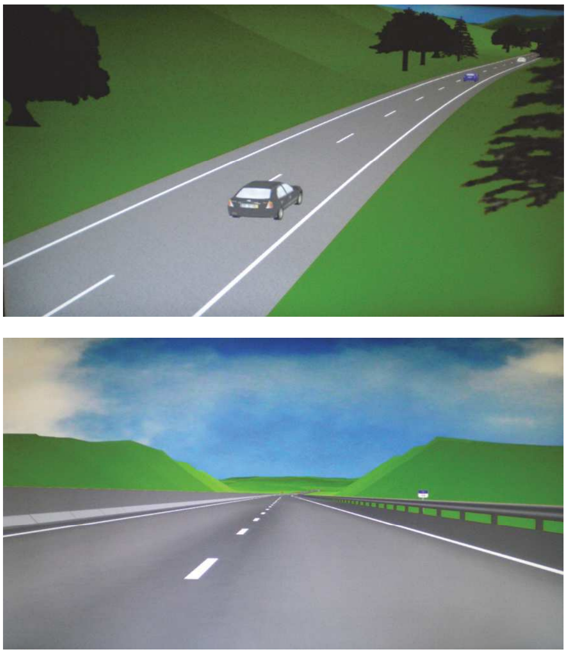


Figure 8: Cut and embankment slopes.

Horizontal signs are made by road marks in the surface of the roads and the vertical signalization are placed in the road environment instancing 3D models, as we can see in figure 9.

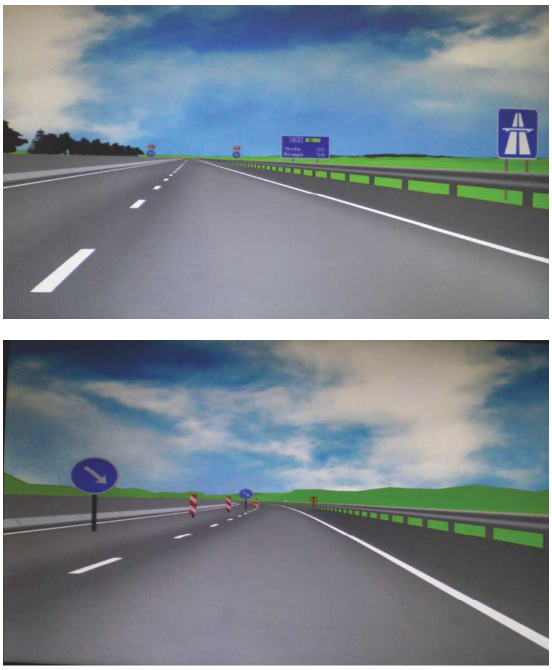


Figure 9: Horizontal and vertical signalization.

A special characteristic of our approach is the efficiency and control, to produces tridimensional models, since the topological road network definition and the road paths of all roads. In table 1, we present the time measured to obtain a topological road definition by our method, with different number of input nodes.

Table 1: Total number of nodes (city, town, village, and interconnection nodes), total length of the roads, time (in seconds) to generate de topological road definition.

Total Nodes	Cities	Towns	Villages	Total Length	Time
142	25	16	15	7620	11
342	25	16	15	12166	76
30	18	0	0	3719.2	2

The trajectory of the roads can be controlled by modifying the parameters of the cost function (section 3.2). In table 2, we present the time measured to obtain road paths with different lengths.

Table 2: Length of the road (in kilometres), time (in seconds).

Length (km)	Design by specialists	Time
1000	1 day	3.42
10000	12 days	19
50000	3 months	52

Making an analysis in terms of time, it is concluded that the proposed method compared to recent methodologies presented by Galin et al. in 2010 (Galin 2010), significantly reduces the time required to generate road paths (15%), maintaining the required standards of realism. This time reduction is more significant in extensive road paths (> 50 km) or in a generation of a large road network, independently of the terrain grid size.

5 CONCLUSIONS

Realistic driving simulation experiments require prior preparation of models of road environments correctly designed, with similar characteristics to those found in real roads. Some experiments also require models that are recognizable as roads from the specific simulated country or region. The presented methodology allows the automatic generation of any type of road environment suitable for driving simulation. It integrates all the road construction stages, from the definition of connecting nodes to the visual model.

The proposed generation process of road layouts was inspired in methods used in roadways engineering, producing roads according to standards and similar to those found in the real world. This is a special contribution of the presented work, that allow minimize the use of specialists for preparing the road paths. The introduction of horizontal curves and vertical curves in altimetry are two prominent factors that contribute to the realism of the road paths obtained.

The problem of generating road paths between two points is globally analysed, at different levels of detail. The final alignment solution generated at each level of detail is determined using the calculation of several costs, by evaluating the relation with the terrain and related constraints, the cost of construction and the cost of use. The cost of use depends with the variation in road layout altimetry (Δz) and the utilization index (section 3.1).

Throughout the automatic generation process, the road layout is successively refined, producing definitions of roadways with the detail required to generate the visual models.

The designed methodology allows obtaining a wide range of road layouts, dramatically reducing work and costs involved in its conception, as it significantly reduces the use of road design specialists to obtain the road network definition as shown by results presented in this paper.

The proposed method eases the inclusion of actors in the simulated environment. This improvement is an innovative contribution to the automatic generation of realistic road environments. A major area of application of this methodology is the generation of road environments that are suitable for driving simulation, allowing the realization of scientific studies in several science areas.

In the near future it will be possible to present resulting road environment to road design experts, in order to best validate the road paths obtained.

ACKNOWLEDGEMENTS

This work had the special contribution of supervisor of the traffic analysis laboratory, where the driving Simulator DriS is implemented, Prof. Dr. Carlos Rodrigues of Civil Engineering Department of FEUP, and Prof. Ângelo Jacob of Civil Engineering Department of ISEP.

The Media Arts and Technologies project (MAT), NORTE-07-0124-FEDER-000061, is financed by the North Portugal Regional Operational Programme (ON.2 – O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF), and by national funds, through the Portuguese funding agency, Fundação para a Ciência e a Tecnologia (FCT).

REFERENCES

Bayarri, S; Fernadez, M; Perez, M, 1996. Virtual Reality for driving simulation, Vol. 39, n.º 5, Communications of the ACM.

Campos, C.; Leitão, J.; Rodrigues, C.; 2007. Modelação de Ambientes Rodoviários de Grandes Dimensões, 15.º Encontro Português de Computação Gráfica.

Campos, C., Leitão, J., Coelho, A.; 2012. Modelação Procedimental de Ambientes Rodoviários para Simulação de Condução, 20.º Encontro Português de Computação Gráfica.

Coelho, António; Bessa, Maximino; Sousa, A. Augusto; Ferreira F. Nunes; 2007. Expeditious modeling of virtual urban environments with geo spatial L-systems; Computer Graphics Forum, Vol. 26, N. 4, pp. 769–782.

Campos, C., Leitão, J., Coelho, A.; 2014. Geração Procedimental de Traçados Rodoviários para Simulação de Condução, 21.º Encontro Português de Computação Gráfica.

Chen,G.; Esch,G.; Wonka,P.; Muller,P.; Zhang,E., 2008. Interactive Procedural Street Modeling, ACM SIGGRAPH.

Donikian, S., 1997. VUEMS: A Virtual Urban Environment Modeling System, Computer Graphics International, Proceedings. IEEE, p. 84-92.

EP, 1994. Book of Road path Standards, Junta Autónoma das Estradas, Estradas de Portugal (EP), ISBN-96379-6-2.

França, A., 2011. Book of roadways, Civil Engineering Department of Engineering Faculty of Porto University.

Galin, E.; Peytavie, A.; Maréchal, N.; Guérin, E., 2010. Procedural Generation of Roads, EUROGRAPHICS, Volume 29.

Galin, E.; Peytavie, A; Guérin, E.; Benes, B., 2011. Authoring Hierarchical Road Networks, Pacific Graphics, Volume 30.

Kelly, G.; McCabe, H., 2008. Citygen: An Interactive System for Procedural City Generation. GDTW, UK.

Latham, R.; Burns, D., 2006. Dynamic Terrain Modification Using a Correction Algorithm, IMAGE 2006 Conference Scottsdale, Ari-zona.

Libtiff, 2014. TIFF Library and Utilities, available at http://www.libtiff.org.

Muller, p.; Wonka, p.; Haegler, S; Ulmer, A.; Gool, L.; 2006. Procedural Modeling of Buildings, ACM SIGGRAPH.

OpenDRIVE, 2010. OpenDRIVE Format Specification rev 1.3, available at www.opendrive.org/docs/

OpenDRIVEFormatSpecRev1.3D.pdf.
Pareja, I.;Bayarri, S.;Rueda, S., 1999. Modelado de calidad para la visualizacióninteractiva de carreteras, IX Congresso de Engenharia Informática.
Parish, Y.; Muller, P., 2001. Procedural Modeling of Cities; ACM Computer Graphics (Proceedings of SIGGRAPH'2001), pp. 301-308.
ROD, 2011. Road generation tool, available at http://www.vires.com/Products_Ted.htm.
Smelik R. M.; Tutenel T.; Kraker K.J.; Bidarra R., 2008. A Proposal for a Procedural Terrain Modelling Framework, EGVE Symposium.
Smelik, R., Tutenel, T., Kraker, J, Bidarra, R., 2011. A declarative approach to procedural modeling of virtual worlds, Computer& Graphics Journal, Elsevier.
Sun, J.; Baciu, G.; Yu, X.; Green, M., 2002. Template-Based Generation of Road Networks for Virtual City Modeling, VRST'02, pp 33-40, NY USA.
Teoh, S., 2008. Algorithms for the Automatic Generation of Urban Streets and Buildings, Proceedings of the International Conference on Computer Graphics and Virtual Reality (CGVR'08).
Thomas, G. and Donikian, S., 2000. Modelling Virtual Cities Dedicated to Behavioural Animation. EUROGRAPHICS 2000, vol. 19(3).
USGS, 2014. United States Geological Survey, available at earthexplorer.usgs.gov.
Vanegas, C. A., Aliaga, D. G., Wonka, P., Müller, P., Waddell, P., & Watson, B. 2010. Modelling the appearance and behaviour of urban spaces. In Computer Graphics Forum (Vol. 29, No. 1, pp. 25-42).
Weber, B.; Müller, P.; Wonka, P.; Gross, M., 2009. Interactive Geometric Simulation of 4D Cities, Eurographics, vol. 28.