Methodology of Training and Support for Urban Search and Rescue With Robots

Janusz Bedkowski, Karol Majek, Igor Ostrowski,
Paweł Musialik, Andrzej Masłowski
Institute of Mathematical Machines IMM
Warsaw, Poland
e-mail: januszbedkowski@gmail.com,
karolmajek@gmail.com, iostrowski@wp.pl,
pawelmus@op.pl, a.maslowski@imm.org.pl

Antonio Coelho
FEUP
INESC TEC
Porto, Portugal
e-mail: acoelho@fe.up.pt

Artur Adamek
Department of Geodesy and Cartography
Warsaw University of Technology
Warsaw, Poland
e-mail: a.adamek@gik.pw.edu.pl

Geert De Cubber
Department of Mechanics MECA
Royal Military Academy
Brussels, Belgium
e-mail: geert.de.cubber@rma.ac.be

Abstract— **A primordial task of the fire-fighting and rescue services in the event of a large crisis is the search for human survivors on the incident site. This task, being complex and dangerous, often leads to loss of lives. Unmanned search and rescue devices can provide a valuable tool for saving human lives and speeding up the search and rescue operations. Urban Search and Rescue (USAR) community agrees with the fact that the operator skill is the main factor for successfully using unmanned robotic platforms. The key training concept is "train as you fight" mentality. Intervention troops focalize on "real training", as a crisis is difficult to simulate. For this reason, in this paper a methodology of training and support for USAR with unmanned vehicles is proposed. The methodology integrates the Qualitative Spatio-Temporal Representation and Reasoning (QSTRR) framework with USAR tools to decrease the cognitive load on human operators working with sophisticated robotic platforms. Tools for simplifying and improving virtual training environment generation from life data are shown.**

Keywords – USAR; robot; training and support; qualitative reasoning

I. INTRODUCTION AND RELATED WORK

The major factor of training determining the acceptance of the USAR community is for the learning process of different tools to conclude within one week, which is the duration of a typical Search and Rescue (SAR) training course. For this reason, it can be difficult to adopt a new training technology if the training requires more than this duration. Training and support is related with effective tasks the robots would be able to do.

In this context, CRASAR, the Centre for Robot-Assisted Search and Rescue from the Texas A&M University, compiled a list of distinct activities for rescue robots [1][2].

The activities and tasks relevant to USAR with unmanned vehicles are: Area reduction, in the early stages of a disaster, there is generally a large area which must be labeled as "possibly affected". To deploy the USAR teams correctly it is required to assess as soon as possible which areas are more affected and which areas are less affected. Sectorization, the disaster area must be subdivided into sectors. Search, robotic tools could speed up the search for victims. Reconnaissance and mapping, robotic tools can help to increase the common operation picture and situational awareness of the deployed teams by mapping the terrain. Rubble removal, robots can remove heavy rubble faster than humans. Debris estimation, after a major crisis, there is in general a lot of debris lying around, impeding the proper deployment of rescue operators and goods. Robots could help with a quicker and better assessment of the most affected zones. Structural inspection and shoring, USAR teams need to assess the structural integrity of a building and may help to stabilize it before entering. On site medical assessment and intervention, robots can provide medical personnel means to inspect a victim remotely via video or audio and to provide the victim life support. Evacuation of casualties, robots may act as carriers to evacuate victims from the disaster area. Acting as mobile beacon or repeater, Robots can help with extending the mobile communication range, by acting as a repeater. Over the horizon applications, Often, SAR teams want to know the damage in a nearby village/suburb/town. It would be highly convenient to be able to send a light Unmanned Aerial System (UAS).

Within the context of mentioned tasks relevant to USAR with unmanned vehicles it is observed that most of these activities can be modeled using a QSTRR [3]. QSTRR proposes the interaction with the environment through a spatial design task. The problem of providing intelligent spatial decision-making capabilities is related to the

framework of Multi-Modal Data Access for Spatial Assistance Systems [4]. This framework shows a key concept of spatial assistance systems by focusing on multi-perspective semantics, qualitative and artefactual abstractions, industrial conformance and interoperability. Authors also provide examples of use for distinct application domains, which was an important input for the developed methodology of training and support. A core concept of artefactual abstractions is to provide qualitative categorization into functional, operational and range spaces [5]. Functional space is a region of space within which a person must be located in, in order to interact with the object or to employ the object for its intended function. Operational space is a region of space that an object requires to perform its intended function. Range space is a region of space where the object operates as a result of performing its intended function. These spaces can model robotic activities in disaster zones.

Another important aspect used in the proposed methodology of training and support is related to geo-referencing of terrestrial laser-scanner data for applications in architectural modeling [6]. Using a 3D laser we can obtain accurate 3D models of the disaster zone, which is the key concept in the proposed USAR-training and support application. From the USAR community point of view, the use of laser scanning can provide frequently updated, accurate and reliable data. In [7] Kurt3D, data from KINECT sensor and Riegl VZ-400 3D scanner are shown, which gives an impression that the State of the Art (SoA) offers efficient mobile platforms equipped with advanced sensors for obtaining accurate maps, that could be used in USAR. Some of these maps are used for semantic objects identification [8]. Using semantic information extracted from 3D laser data is a relatively recent research topic in mobile robotics. In [8] a semantic map for a mobile robot was described as a map that contains, in addition to spatial information about the environment, assignments of mapped features to entities of known classes. In [9] a model of an indoor scene is implemented as a semantic net. This approach is used in [10] where a robot extracts the semantic information from 3D models built from a laser scanner.

The proposed methodology of training and support is adopting procedural modeling tools [11][12] that can be used for the generation of virtual urban environments, reducing both the amount of interaction needed as well as modeling effort. These techniques can be enhanced to generate accurate models that incorporate the semantic data existing in Geographic Information System (GIS) [13][14]. On the other hand, municipalities often store several semantic data regarding the urban features populating the territory in a GIS. Procedural modeling of urban environments originates from the use of L-Systems [15]. The limitations of this mathematical tool led to the development of the CGA Shape [16], a shape grammar capable of producing extensive architectural models with high detail. The implementation of the CGA Shape is integrated in the CityEngine framework. The same limitation led to the development of Geospatial L-Systems [17], an extension of parametric L-Systems which incorporates spatial awareness. This approach combines the ability of data amplification provided by the L-Systems with the geospatial awareness of GIS. Approach proposed in this paper combines procedural modeling tools, Qualitative Spatio-Temporal Representation and Reasoning framework and modern laser scanning to provide methodology for training and support for robotic USAR application.

The paper is organized as follows: Section II describes the use of QSTRR framework for purpose of semantic modeling, Section III concentrates on procedural modeling of urban environments, Section IV, V and VI describe data processing and conceptualization, experiments conducted are described in Section VII, finally Section VIII contains conclusion and future work description.

II. SEMANTIC MODEL OF USAR OPERATION

To model an USAR operation, the QSTRR is proposed. The main element is an ontology. As a representation vocabulary it is specialized to the domain of physical/functional entities in real structured environment. It allows to build a model of an environment using qualitative spatio-temporal or quantitative (depends on the need) representation. An ontology (O) is composed of several entities: a set of concepts (C), a set of relations (R), a set of axioms (A) (e.g., transitivity, reflexivity, symmetry of relations), a concepts' hierarchy (CH), a relations' hierarchy (RH), a set of spatio-temporal events (Est), what can be formulated as following definition:

$$O = <C;R;A;CH;RH;Est> \qquad (1)$$

A concept is defined as a primitive spatial entity described by a shape (S) composed of polygons in 3D space associated with a semantic label (SL). Ontology distinguishes two different types of attributes that can be assigned to a concept, quantitative (Aqn) and qualitative (Aql). Four values of qualitative attribute (entity function) are listed: real physical object, functional space, operational space, range space. Functional, operational and range spaces are related with spatial artifacts that describe the USAR environment and robotic devices such as sensors and actuators. Quantitative attributes are related with physical properties of spatial entities and are as follows: location, mass, center of mass, moment of inertia (how much resistance there is to change the orientation about an axis), material (friction, restitution). Therefore, the definition of the concept (C) is formulated as:

$$C = <S;Aqn;Aql; SL> \qquad (2)$$

The set of relations (R) is composed of quantitative and qualitative spatial relations. For topological spatial relations
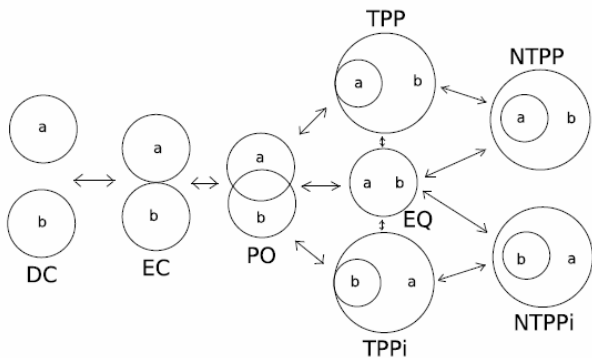
Figure 1.   The relations of RCC-8 calculus (conceptual neighborhood).

(qualitative) the Region Connected Calculus (RCC) is proposed. RCC is a formalism for spatial reasoning that takes regions of space (shapes) instead of points of classical geometry as primitives. One particular prominent reasoning system is a system of topological relations called RCC8(the relations of RCC-8 calculus and conceptual neighborhood is shown in Figure 1, therefore the ontology includes eight different topological relations between two regions (in our case shapes): disconnected (DC), externally connected (EC), partial overlap (PO), equal (EQ), tangential proper part (TPP) and its inverse (TPPi), non-tangential proper part (NTPP) and its inverse (NTPPi).

Quantitative spatial relations are a way to constrain the way entities move relative to each other. The ontology defines the following constraints: origins locked, orientations locked; origins locked, orientations free; free rotation around one axis; sliding. Ontology provides a mechanism for building world models that assume spatio-temporal relations in different time intervals (in other words: world models that can capture changes) for the representation of spatio-temporal knowledge used for spatiotemporal reasoning. Chosen temporal representation takes temporal intervals as a primitive, therefore ontology defines qualitative spatio-temporal events (Est) related with topological spatial relations RCC-8:

onEnter (DC->EC->PO),

onLeave(PO->EC->DC),

onStartInside(PO->TPP->NTPP),

onStopInside(NTPP->TPP->PO).

These four qualitative spatio-temporal events can be used to express most important spatio-temporal relations that can be held between two concepts in different intervals of time. To store the instances of ontology-based elements (defined on the conceptual level) an instance base (IB^O) is defined:

$$IB^O = <I^O_C ; I^O_R ; I^O_{Est}> \qquad (3)$$

where: I^O_C contains instances of concepts C, I^O_R contains instances of relations R, I^O_{Est} contains instances of spatio-temporal events. Semantic model is defined as a pair:

$$SM =<O; IB^O> \qquad (4)$$

where: O is an ontology and IB^O is an instance base related to ontology O. Ontology is known a-priori but instance base is being updated during USAR operation. Semantic model is

Figure 2.   City model generated from municipal GIS

a core concept for support system. The projection of the semantic model onto 3D space is defined as 3D semantic map, and the projection of the semantic model onto 2D space is defined as 2D semantic map. Semantic maps are useful visualization tools for increasing the awareness of search teams concerning the global operational picture of the USAR scenario.

III.   PROCEDURAL MODELING TOOLS FOR THE GENERATION OF VIRTUAL URBAN ENVIRONMENTS

Procedural methods require that the user, capturing the knowledge about the modeling process, introduces some guidelines and rules. This is time consuming and can be difficult to develop in a crisis situation. By taking advantage of the semantic model for USAR operation this approach uses generic production rules to amplify available data from existing shapes or general information.

In this sense, some methods have already been conceived, but as far as control is concerned, procedural ways still lack powerful picking and manipulation facilities to apply geometric operations. This motivates the development of more advanced methodologies for such control.

Based on PGCAD API [12], a solution for geometric manipulation in procedural modeling tools that incorporates spatial awareness and semantic control, it is possible to achieve more powerful control over geometric entities based on their properties and sequential application of modeling operations, therefore allowing a greater, faster and more intuitive approach for geometry generation. This is achieved through its intuitive topological structure, which features a set of properties, such as scope, spatial awareness and semantic information. The modeling processes can be massively applied to sets of shapes, yet act according to each individual shape's properties. This allows a more customized control, as well as successive tracking, which induce a greater, faster and more intuitive approach for geometry generation.

IV. REAL TIME 3D DATA PROCESSING

The goal of support system is to increase the awareness of rescue team concerning a disaster sector. For this reason, a data filtering and registration tool is developed [18]. Figures 3 and 4 demonstrate the computation of 3D clouds obtained with a modern 3D laser scanner (each cloud contains 1,5 million of data points).
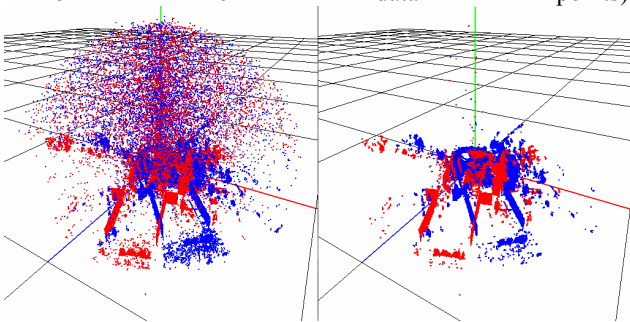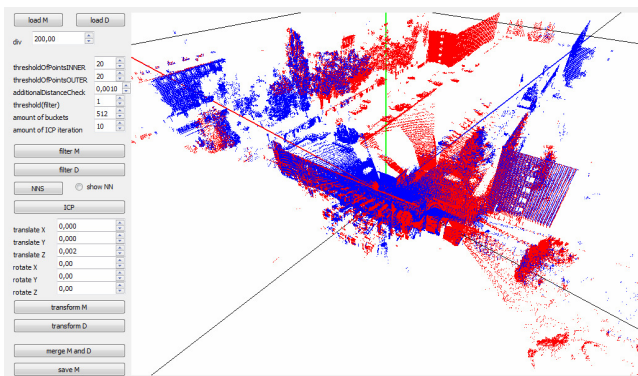

Figure 3.   The filtering of 2D cloud of points.

Figure 4.   The registration of 3D cloud of points.

The computation time of filtering is on average 1,2 second, the registration takes in average 2 minutes assuming computational help of the ICP (Iterative Closest Point) algorithm. It is important to emphasize that the proposed approach can register up to 65million of points within 30 minutes.

V. MANUAL CONCEPTUALISATION

The proposed support system provides the functionality of manual conceptualization based on the registered 3D cloud of points (Figure 5). Rescue team members will have the possibility to assign semantic labels to the observed objects.
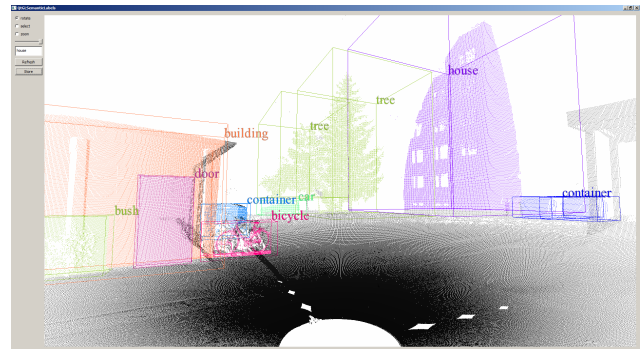

Figure 5.   The view of HMI for manual conceptualisation.

These labels correspond to the spatial regions in the 3D scene will generate additional semantic concept in the semantic model of global operational picture that is distributed over USAR system.

VI. AUTOMATIC CONCEPTUALISATION

To decrease the cognitive load on rescue team members, the proposed support and training system provides a mechanism for automatic conceptualisation based on artificial intelligence techniques. In its current form, the system classifies each point into one of four classes: ground, building, vegetation, unclassified. The assignment is made by analysing normal vectors of points. The first step concentrates on finding the post populous horizontal plane, below the origin point of the scan. To achieve this, a RANdom SAmple Consensus (RANSAC) [19] method is used. After that, each point whose distance to the found plain is lower then R is classified as ground. Those points are then filtered out from the data 3D point cloud. Remaining points are grouped into cells of 2x2 meters, in the horizontal plane. They main assumption, on which classification between vegetation and buildings is made is that buildings are mostly regular plains, whereas trees and bushes are mostly irregular group of points. Therefore, a cell that holds vegetation points should have a roughly uniform distribution of directions of normal vectors, and cell that holds building walls should have most normal vectors pointing in one direction. Based on that reasoning the cells are classified in two groups: potential building or potential vegetation. The cell is considered potential building if normal vectors of at least half of the points in the cell point in roughly the same direction. In such cell RANSAC algorithm is used to see if such a plane can be found that at least half of the points in the cell is in N-distance of it. If this condition is met, the cell is classified as a building. Every cell that does not meet this condition is added to the group of potential vegetation. The vegetation hypothesis is checked by counting the dominant direction of normal vectors of each point in the cell. If the distribution of normal vectors directions is roughly uniform, the cell is considered vegetation. The cells that do not meet this condition are classified as unclassified. After initial classification, every cell is checked, by comparing it with it's neighbors.
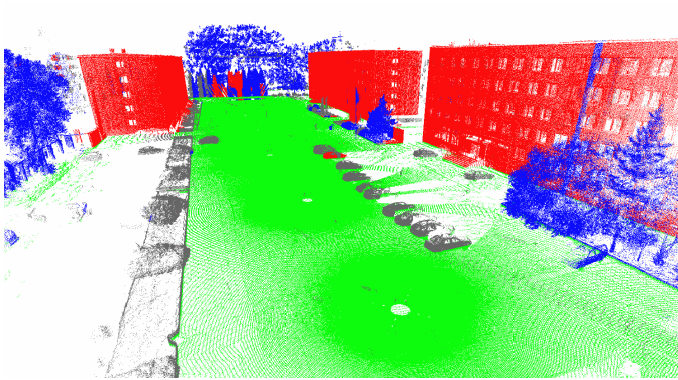
Figure 6.   The view of HMI for the visualisation of automatic conceptualisation.

The results of the algorithm are shown in Figure 6. Classes of points are shown by color: green-ground, red-building, blue-vegetation, gray-unclassified. Computation time for 15 million points cloud for this particular experiment is 50s.

VII.   EXPERIMENT

To proof the concept of qualitative reasoning used in USAR with robots, we validate the methodology in the environment shown in Figure 7. Each cell corresponds to a 10x10 meter rectangle. Therefore, the global operational picture covers region of 200x200 meters. The semantic model contains 3D shapes of the scanned real objects, robot goals (starting point, middle goal, and destination goal), robot path – rectangular prisms – 3D shapes between goals, robot shape and artificial cameras (Figure 8). The projections of the semantic model onto 3D and 2D spaces are shown in Figures 9 and 10. These projections are defined as semantic maps, which are to be visualized for rescue team members to increase their awareness of global operational picture. The qualitative reasoning capabilities for the given example can be demonstrated using the following request-respond pairs.

Request: where is the robot?

Qualitative respond: robot is inside the path.

Quantitative respond: robot's GPS(Global Positioning System) coordinates.

When human operator will try to omit the path support system will respond:

Qualitative respond: robot is going out of the path.

Quantitative respond: robot's GPS coordinates.
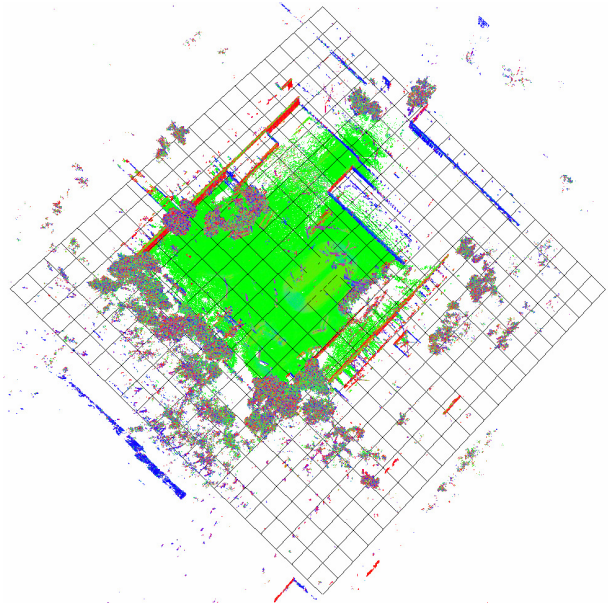

Figure 7.   Testing environment - the registetred 3D cloud of points.
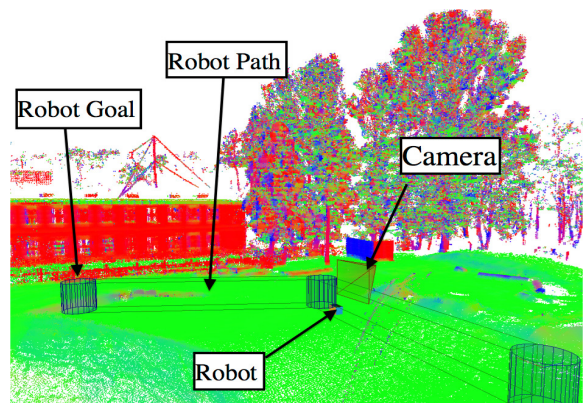

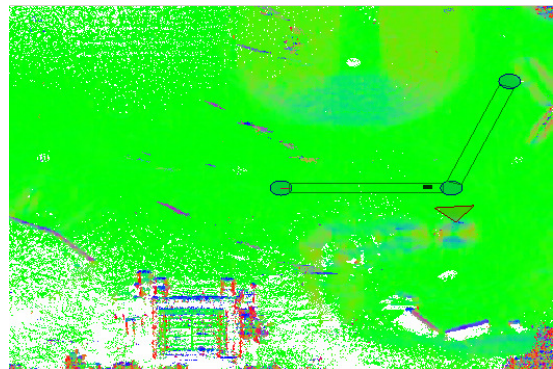Figure 8.   Visualisation of the semantic model.

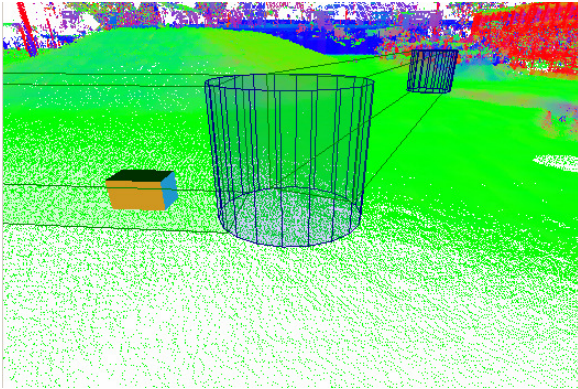Figure 9.   2D semantic map of semantic model from Figure 7.

Figure 10. 3D semantic map of semantic model from Figure 7. The view point - range space of artificial camera.

Based on these simple examples it can be observed that qualitative reasoning capabilities are very useful for rescue team members because of its simple form. It is important to simplify the use of advanced technologies which can help to introduce new modules into the USAR community.

VIII. CONCLUSION

In this paper, a methodology for training and support for Urban Search and Rescue with robots is shown. The methodology integrates the QSTRR framework with USAR tools for decreasing the cognitive load on human operators working with sophisticated robotic platforms. The goal was to develop software component for filtering and registering 3D data acquired with modern 3D laser scanner (providing millions of points in a single 3D scan). Registered data is manually or automatically conceptualized, providing a semantic model associated with a global operational picture. Through the modification of this semantic map, we can model complex USAR scenarios, assuming the usage of the robotic platforms.

ACKNOWLEDGMENT

REFERENCES

[1] J. Burke, R. Murphy, E. Rogers, V. Lumelsky, and J. Scholtz , "Final report for the RARPA/NSF interdisciplinary study on Human-Robot Interaction" IEEE Transactions on Systems, Man, and Cybernetics - Part C: Applications and Reviews, Vol.34, No. 2, 2004, pp. 103-112.

[2] J. Carlson, R. Murphy, and A. Nelson, "Follow-Up analysis of mobile robot failures," CRASAR Technical Report - TR2004-10, 2004.

[3] J. Będkowski, "Intelligent mobile assistant for spatial design support," Journal of Automation in Construction, 2012, doi: http://dx.doi.org/10.1016/j.autcon.2012.09.009

[4] C. Schultz and M. Bhatt, "A multi-modal data access framework for spatial assistance systems: use-cases with the building information model (bim/ifc)," ISA, Proc. 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness, 2010, pp. 39-46.

[5] M. Bhatt, F. Dylla, and J. Hois, "Spatio-Terminological interference for the design of ambient environments," in Conference on Spatial Information Theory(COSIT'09), K. S. Hornsby, C. Claramunt, M. Denis, and G. Ligozat, pp. 371-391, Springer-Verlagm, 2009.

[6] S. Schuhmacher and J. Bohm, "Georeferencing of terrestrial laserscanner data for applications in architectural modeling," 3D-ARCH 2005: Virtual reconstruction and visualization of complex architectures, Mestre-Venice, Italy, 22-24 August, 2005, Univesitat Stuttgart, 2005, URL: http://elib.uni-stuttgart.de/opus/volltexte/2007/3256

[7] J. Elseberg, D. Borrmann, and A. Nuchter, "Efficient processing of large 3d point clouds," Proc. XXIII International Symposium on Information, Comunication and Automation Technologies(ICAT11), Srajevo, Bosnia, 2011, pp. 1-7

[8] A. Nuchter and J. Hertzberg, "Towards semantic maps for mobile robots," Robot. Auton. Syst., vol. 56, no. 11, 2008, pp. 915-926, doi: 10.1016/j.robot.2008.08.001. URL: http://dl.acm.org/citation.cfm?id=1453261.1453481

[9] O. Grau, "A scene analysis system for the generation of 3-d models," NRC '97, Proc. International Conference on Recent Advances in 3-D Digital Imaging and Modeling, IEEE Computer Society, Washington, DC, USA, 1997, p. 221-228.

[10] A. Nuchter, H. Surmann, K. Lingemann, and J. Hertzberg, "Semantic scene analysis of scanned 3d indoor environments," Proc. Eighth International Fall Workshop on Vision, Modeling, and visualization (VMV 03), 2003, pp. 665-673.

[11] P. B. Silva, A. Coelho, R. Rodrigues, and A. A. de Sousa, "A procedural geometry modeling API," Proc. GRAPP & IVAPP 2012, Italy, SciTePress 2012, 24-26 February, 2012, pp. 129-134.

[12] P. B. Silva and A. Coelho, "Procedural modeling for realistic virtual worlds development," Journal of Virtual Worlds Research, vol. 4 , no. 1, 2011 , doi:10.4101/jvwr.v4i1.2109

[13] D. Jesus, A. Coelho, C. Rebelo, A. Cardoso, and A. A. Sousa, "A pipeline for procedural modelling from geospatial data." Proc. Eurographics 2012, pp. 9-10, 2012.

[14] T. Martins, P. B. Silva, A. Coelho, and A. A Sousa, "An urban ontology to generate collaborative virtual environments for municipal planning and management," Proc. GRAPP 2012 -7th International Conference in Computer Graphics Theory and Applications, pp. 507-510, 2012.

[15] Y. I. H. Parish and P. Müller, "Procedural modeling of cities." Proc. 28th annual conference on Computer graphics and interactive techniques(SIGGRAPH '01), ACM, New York, USA, 2001, pp. 301-308.

[16] P. Müller, P. Wonka, S. Haegler, A. Ulmer, and L. van Gool, "Procedural modeling of buildings" ACM Trans Graph., vol. 25, July 2006, pp. 614-623.

[17] A. Coelho, M. Bessa, A. A. Sousa, and F. N. Ferreira, "Expeditious modeling of virtual urban environments with geospatial l-systems," Computer Graphics Forum, vol. 26, no. 4, 2007, pp. 762-782.

[18] J. Będkowski, A. Masłowski, and G. De Cubber, "Real time 3D localization and mapping for USAR robotic application," Industrial Robot: An International Journal, vol. 39, no. 5, 2012, pp. 464-474.

[19] M. A. Fischler and R. C. Bolles,"Random Sample Consensus: A paradigm for model fitting with applications to image analysis and automated cartography," Comm. of the ACM, vol. 24, no. 6, june 1981, pp. 381–395, doi :10.1145/358669.358692 .