Comparative Analysis of State-of-the-Art Spatial Data Warehouse Meta-models

Catching the Expressive Power of SDW Schemas!

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Abstract: In this paper we provide a comparative analysis of the Spatial Data Warehouse Metamodel (SDWM) proposal against three state-of-the-art Spatial Data Warehouses (SDW) meta-model proposals. Results of this analysis allow us to conclude that the SDWM proposal exposes a higher expressive power of the comparison approaches, and, in addition to this, it allows us to obtain more concise and compact SDW schemas when compared with the schemas provided by the comparison approaches.

1 INTRODUCTION

Spatial Data Warehouse Metamodel (SDWM) (Del Aguila et al., 2011; Cuzzocrea & Fidalgo, 2012a; Cuzzocrea & Fidalgo, 2012b) has been provided recently with the goal of effectively supporting the modeling of *Spatial Data Warehouses* (SDW) (Bédard et al., 2001; Zghal et al., 2003) by adding several contributions. Among these, relevant ones concern with separating the SDW conceptual modeling from the *OLAP data cube* (Gray et al., 1997) conceptual modeling, supporting SDW complex constructs modeling, and, finally, stereotyping attributes and measures as *spatial objects* directly.

Another nice contribution due to this line of research is represented by the proposal of a software environment, called SDWCASE, which allows us to model a SDW according to the SDW's design and modeling principles, in a user-friendly manner.

As a further research effort along the so-depicted line of research, in this paper we provide a *comparative analysis* of the SDWM proposal against three state-of-the-art SDW meta-model proposals (Fidalgo et al., 2004; Malinowski & Zimányi, 2007; Glorio & Trujillo, 2008).

Results of this analysis allow us to conclude that the SDWM proposal exposes a higher expressive power of the comparison approaches, and, in addition to this, it allows us to obtain more concise and compact SDW schemas when compared with the schemas provided by the comparison approaches.

The remaining part of this paper is organized as follows. In Section 2, we provide an overview of the SDWM proposal. In Section 3, we introduce a running example focusing on a SDW of homicide cases for the secretary of the Public Safety Office of Pernambuco/Brazil. Next Sections 4-6 are devoted to the comparative analysis of SDW with the comparison approaches: (Fidalgo et al., 2004) (Section 4), (Malinowski & Zimányi, 2007) (Section 5), and (Glorio & Trujillo, 2008) (Section 6). In Section 7, we provide the results of the comparative analysis that is the main contribution of our research. Finally, in Section 8, we provide conclusions and future work of our research.

2 SDWM IN A NUTSHELL

SDWM (Del Aguila et al., 2011; Cuzzocrea & Fidalgo, 2012a; Cuzzocrea & Fidalgo, 2012b) is a meta-model that embeds the following significant features: (*i*) disassociating DW dimensional modeling from OLAP data cube modeling; (*ii*) representing the spatiality of a SDW by directly stereotyping attributes/measures as spatial types, rather than stereotyping dimension/fact tables as spatial or hybrid objects; (*iii*) capturing whether the

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geometry of a spatial attribute/measure can be normalized and/or shared; (*iv*) supporting the following DW modeling techniques: degenerated dimensions, many-to-many relationships (bridge tables), role-playing dimensions, which are typically-hard modeling cases (Bédard et al., 2001; Zghal et al., 2003); (*v*) providing a set of stereotypes with pictograms that aim at being concise and user-friendly; (*vi*) being used as a basic meta-model for the CASE tool SDWCASE that supports the modeling of logical SDW schemas, as well as, given an input SDW schema, checking whether the schema is syntactically valid.

In Figure 1, the UML class diagram of SDWM is shown. Here, three relevant enumerations are introduced: *Cardinality*, *DataType* and *GeometricType*. *Cardinality* is used to define whether a relationship is of kind *many-to-one, one-to-many* or *many-to-many*. In turn, *DataType* and *GeometricType* represent the primitive or spatial data types supported by SDWM, respectively. Moreover, SDWM exposes five main meta-classes: *Schema*, *Table*, *Relationship*, *DimensionColumn* and *FactColumn*. *Schema* is the root meta-class that corresponds to the drawing area for a SDW schema. For this reason, *Schema* is a composition of zero or more *Table* and zero or more *Relationship*. Finally, *DimensionColumn* and *FactColumn* are just a set of different types of column.

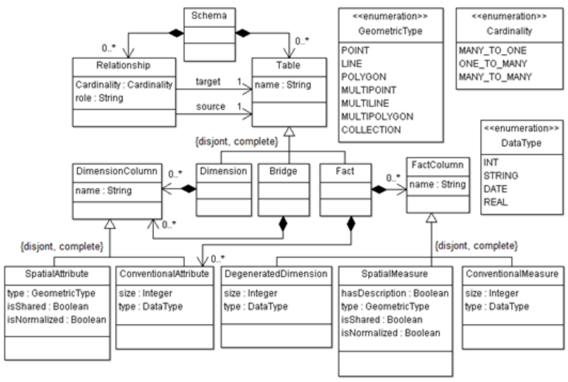

Figure 1: SDWM UML class diagram.

Besides the previous constructors, SDWM is also characterized by the following eight specialized meta-classes (see Figure 1): *Fact*, *Dimension*, *Bridge*, *SpatialMeasure*, *DegenerateDimension*, *ConventionalMeasure*, *SpatialAttribute* and *ConventionalAttribute*. These meta-classes address the main concepts supported by the SDWM modeling approach. On the basis of this approach, a *Table* is specialized in *Fact*, *Dimension* or *Bridge*, which capture the concepts of (SDW) fact table, dimension table and a bridge table, respectively. A *FactColumn* is specialized in *SpatialMeasure*, *DegenerateDimension* and *ConventionalMeasure*, which correspond to a spatial feature type, a descriptive attribute and a measurable attribute, respectively. A *DimensionColumn* is specialized in *SpatialAttribute* and *ConventionalAttribute*, which represent a spatial feature type and a descriptive attribute, respectively. Furthermore, a *Fact* is a composition of zero or more *FactColumn* and zero or more *ConventionalAttribute*. In turn, a *Dimension* and a *Bridge* are a composition of zero or more *DimensionColumn*.

In order to capture tables that are source and target in a relationship, SDWM introduces two different associations, named as *Source* and *Target*, respectively. Furthermore, since a dimension can play different roles (role-playing dimensions), SDWM introduces the attribute *Role* to support this specialized modeling case. Other important SDWM attributes are: *Name*, *isNormalized*, *isShared*, *hasDescription, Type* and *Size*. *Name* is used to label a meta-class. *IsNormalized* is used to define whether the position (geometry) of a spatial measure/attribute has to be normalized in a different table from its location (description). *IsShared* is used to define whether the position of a spatial attribute/measure has to be shared among several spatial attributes/measures (to this end, it is necessary to define the *same* name and the *same* geometric type). *HasDescription* is used to define whether the location of a spatial measure has to be stored (contrary to a *SpatialAttribute*, which must have a position and a location, the location of a *SpatialMeasure* is optional). *Type* is used to associate a type (from the collection of allowed SDWM types). Finally, *Size* is used to define the length of a conventional attribute, a degenerated dimension or a conventional measure.

SDWM makes use of stereotypes with pictograms in order to increase its expressive power and visualization capabilities, namely: *Fact Table* Ft, *Dimension Table* Dt, *Bridge Table* Bt, *Conventional Attribute* C, *Conventional Measure* C, *Degenerated Dimension* d, *Spatial Attribute* S, *Spatial Measure* S, *Relation*, *Integer* int, *String* str, *Date* dt, *Real* rl, *Point*, *Line*, *Polygon*, *Multipoint*, *Multiline*, *Multipolygon*, *Collection*. The combined action of these stereotypes allows us to design "rich" SDW schemas.

3 RUNNING EXAMPLE: THE HOMICIDE SDW

In order to assess the effectiveness of the proposed SDWM approach, we developed a complete case study focused on a SDW of homicide cases for the secretary of the Public Safety Office of Pernambuco/Brazil. This originated quite a complex schema. A fragment of this schema designed by means of SDWCASE is shown in Figure 2.

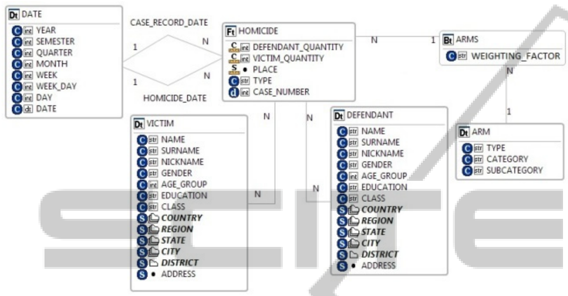

Figure 2: Fragment of the homicide SDW according to SDWM.

As shown in Figure 2, the homicide SDW is characterized by the following DW objects. Four dimension tables: *Date*, *Victim*, *Defendant* and *Arm*, which are stereotyped with . One bridge table: *Arms*, which is stereotyped with . One fact table: *Homicide*, which is stereotyped with . Two role-playing dimensions: *Case_Record_Date* and *Homicide_Date*. Two many-to-many relationships: one between *Homicide* and *Victim* and another between *Homicide* and *Defendant*. Four one-to-many relationships: two between *Homicide* and *Date*, one between *Homicide* and *Arms*, and one between *Arms* and *Arm*. One degenerated dimension: *Case_Number*, which is stereotyped with . Two conventional measures: *Defendant_Quantity* and *Victim_Quantity*, which are stereotyped with . One spatial measure: *Place*, which is stereotyped with . Twenty-seven conventional attributes, such as *Year*, *Weighting_Factor*, *Name* and *Date*, which are stereotyped with , , and , respectively. Twelve spatial attributes, such as *Country*, *District* and *Address*, which are stereotyped with , and , respectively.

It is worth to noticing that, in the schema of Figure 2, spatial attributes *Country*, *Region*, *State* and *City* are defined as normalized (depicted with bold font) and shared (depicted as Italic font). According to the SDWM modeling approach, this means that these spatial attributes have their geometries stored in a table different of the table containing their descriptions, and their geometries can be reused between the dimensions *Victim* and *Defendant*. This solution aims at reducing the overall spatial data volume of the homicide SDW.

4 COMPARISON WITH (FIDALGO ET AL., 2004)

(Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) introduce a framework, a meta-model and a CASE tool for modeling SDW. The proposed meta-model is depicted in Figure 3 (da Silva et al., 2010) while the logical model of a SDW focusing on meteorology data (which makes use of their proposed CASE tool) is showed in Figure 4 (Times et al., 2009).

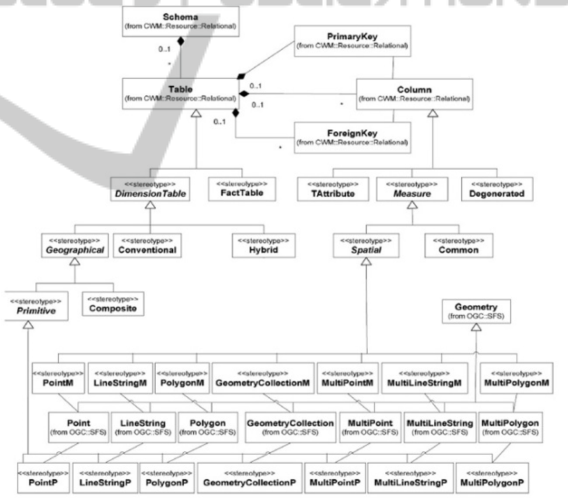

Figure 3: SDW meta-model proposed by (Fidalgo et al., 2004).

As shown in Figure 3, the meta-model proposed by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) introduces classical constructs useful to model a SDW, i.e.: attributes, measures, degenerated dimensions, primary keys, foreign keys, common measures, spatial measures, geographical dimensions, conventional dimensions, hybrid dimensions and fact tables. However, this models is not totally complete as some important constructs are still missing. Particularly, these constructs are: many-to-many relationships (bridge tables), role-playing dimensions and spatial attributes. These constructs, indeed, are very useful to model real-life SDW, like the case of our running example focusing on the homicide SDW (see Figure 2). As a consequence, we can infer that the meta-model by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) does not provide a full-support for modern SDW.

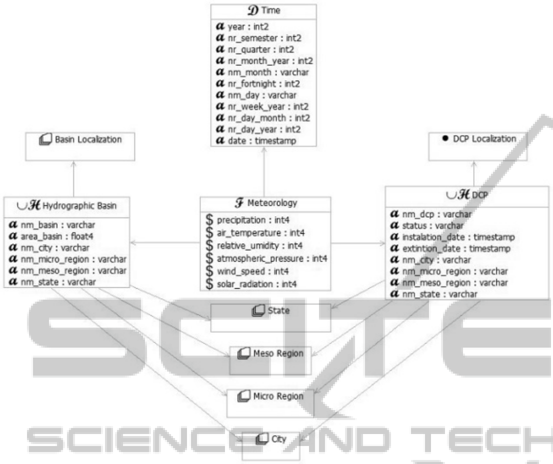

Figure 4: Meteorology SDW according to (Fidalgo et al., 2004).

As mentioned above, Figure 4 show the logical model of the meteorology SDW designed by means of the CASE tool by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010), which, obviously, adheres to their proposed meta-model. Here, one fact table is defined, i.e. *Meteorology*, and nine dimensional tables, i.e. *Hydrographic Basin*, *Basin Location*, *Time*, *Data Collection Platform* (*DCP*), *DCP Location*, *State*, *Meso Region*, *Micro Region*, *City*. As shown in Figure 4, fact table *Meteorology* has only conventional measures (i.e., *precipitation* and *wind_speed*) and dimension tables have both conventional (i.e., *nm_basin* in *Hydrographic Basin* and *year* in *Time*) and spatial (i.e., *state* in *State* and *dcp_location* in *DCP Location*) attributes. Moreover, the use of dimensions stereotyped with spatial pictograms (i.e., *Meso Region* and *Micro Region*) does not provide a concise/short notation, as, for each spatial concept, one dimension is introduced. It is worth to notice that this approach pollutes the SDW schema as it results in an excessive and redundant number of spatial concepts immersed in the schema.

Figure 5 shows the meteorology SDW of Figure 4 modeled by means of SDWCASE according to SDWM. This originates a SDW schema that is equivalent to the schema of Figure 4. As an alternative to the modeling due to (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) (see Figure 4), in the SDWM modeling (see Figure 5) we introduce *city*, *micro_region*, *meso_region* and *state* as spatial attributes directly and their geometries are normalized and shared between the dimensions *Hydrographic Basin* and *DCP*. As is clearly follows from the comparison between the two schemas in Figure 4 and Figure 5, the use of spatial attributes improves representation of the meteorology SDW (and, in turn, its "visual quality") by achieving a more compact one, as six dimensions are no longer modeled (i.e., *Basin Location*, *DCP Location*, *State*, *Meso Region*, *Micro Region*, *City*).

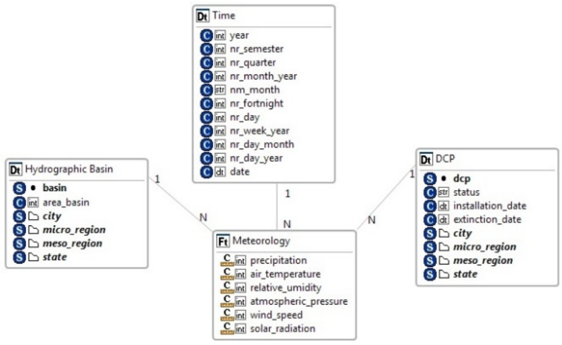

Figure 5: Meteorology SDW according to SDWM.

On the other hand, from Figure 4 it also follows that the meta-model proposed by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) does not mix the DW modeling concepts with the OLAP data cube ones, similarly to the proposed meta-model SDWM. This is, indeed, a positive contribution.

Summarizing, from the results of this analysis we can conclude that, with respect to the meta-model proposed by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010), the proposed meta-model SDWM is capable of achieving equivalent SDW schemas in a much more compact and concise way, thanks to the fact it can immerse spatial attributes (and their geometries) directly into dimensions, hence the expressive power of the SDWM proposal is clearly higher.

5 COMPARISON WITH (MALINOWSKI & ZIMÁNYI, 2007)

Malinowski & Zimányi (2007; 2009) propose a SDW meta-model that introduces dimensions, hierarchies, levels and measures, which all can be spatial or not by simply declaring a Boolean specifying state variable called *Spatiality*. The SDW logical models adhering to such a meta-model are represented as suitable extensions of the classical ER model. Figure 6 (Malinowski & Zimányi, 2009) shows the UML class diagram for the meta-model proposed by Malinowski & Zimányi (2007; 2009). As it follows from Figure 6, this meta-model mixes DW modeling concepts with OLAP data cube modeling ones, and it does not provide support for the following DW modeling techniques: degenerated dimensions, bridge tables (many-to-many relationships) and role-playing dimensions. As a consequence, the meta-model by Malinowski & Zimányi (2007; 2009) does not allow a full modeling of the homicide SDW of the running example (see Section 3). In fact, this meta-model neither allows specifying whether the geometry of a spatial attribute can be normalized and/or shared nor provides support for modeling the previously-mentioned DW modeling techniques (which are frequent cases in real-life SDW settings). Moreover, to the best of our knowledge, there is no a CASE tool based on this meta-model. This is another relevant limitation of the proposal by Malinowski & Zimányi (2007; 2009).

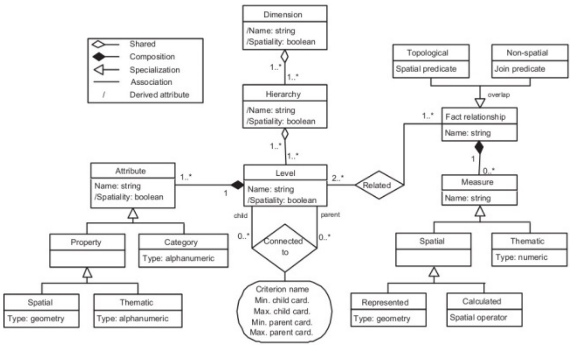

Figure 6: UML class diagram of the SDW meta-model proposed by (Malinowski & Zimányi, 2007).

Figure 7 (Malinowski & Zimányi, 2007) shows the logical model of a highway SDW according to the proposal due to Malinowski & Zimányi (2007; 2009). As shown in Figure 6, the SDW schema introduces one fact table, called *Highway Maintenance*, with is characterized by conventional and spatial measures (e.g., *No. cars* and *Common area*), and dimensions/levels (e.g., *Highway* and *Highway Segment*) with conventional and spatial information (e.g., *Road condition* and *State*). From Figure 7, it follows that representation of levels as entities (it should be reminded that in this case ER extensions are considered), besides being not correspond to an intrinsic concept of DW, it does not provide a concise representation/notation, as, according to this approach, it is necessary to create an entity for each level, hence polluting the SDW schema significantly.

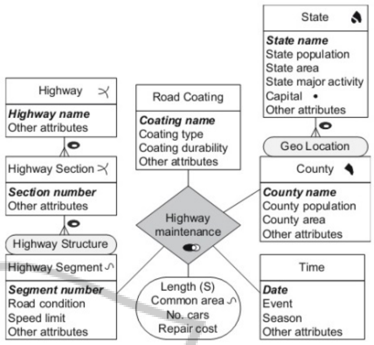

Figure 7: Highway SDW according to (Malinowski & Zimányi, 2007).

Figure 8 shows the highway SDW of Figure 7 modeled by means of SDWCASE according to SDWM. Again, the two schemas are equivalent. Since, from Figure 7, it is not possible to know whether the geometry of a spatial object is normalized or shared, in the logical model of the highway SDW according to SDWCASE of Figure 8, we simply define all geometries as not normalized and not shared. As a consequence, the SDW schema of Figure 8 is characterized by significant redundancy of geometric information, which, in turn, increases the whole data volume of the final SDW and, in addition to this, the SDW administration itself becomes more difficult. Similarly to the case of the comparison of SDWM with the meta-model proposed by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) (see Section 4), here we again observe the clear advantages deriving from immersing spatial attributes (and their geometries) into dimensions directly. In fact, in the highway SDW according to SDWM (see Figure 8) we employ four dimensions only whereas in the highway SDW according to Malinowski & Zimányi (2007; 2009) (see Figure 7) seven dimensions are necessary to represent the same knowledge. This comparison clearly is in favor of SDWM, which is capable of representing the same knowledge in a more compact and concise way.

Summarizing, from the results of this analysis we can conclude that, with respect to the meta-model proposed by Malinowski & Zimányi (2007; 2009), the proposed meta-model SDWM exposes a clearly-higher expressive power, as the meta-model due to

Malinowski & Zimányi (2007; 2009) does not address some important DW modeling techniques (i.e., degenerated dimensions, bridge tables and role-playing dimensions) and also it does not allow to specify whether the geometry of a spatial attribute can be normalized and/or shared among dimensions, thus preventing a full modeling of our running example on the homicide SDW. In addition to this, the meta-model due to Malinowski & Zimányi (2007; 2009) introduces an entity for each dimensional level, hence it clearly reduces the clarity and the comprehensibility of final SDW schemas (this drawback is much more evident with real-life SDW schemas that are usually characterized by high numbers of dimensions and dimensional attributes). Finally, Malinowski & Zimányi (2007; 2009) do not propose any CASE tool adhering to their meta-model, like the SDWM proposal.

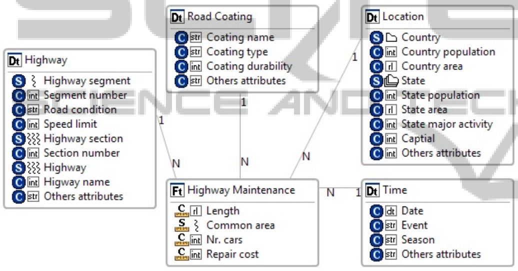

Figure 8: Highway SDW according to SDWM.

6 COMPARISON WITH (GLORIO & TRUJILLO, 2008)

Glorio & Trujillo (2008; 2009) extend the UML meta-model in order to define a *UML profile* enriched with a set of stereotypes for dimensions, facts, conventional measures, spatial measures, degenerated dimensions, conventional levels and spatial levels. Figure 9 (Glorio & Trujillo, 2009) shows the obtained SDW-aware UML profile. Moreover, based on the proposed UML profile, they also build a CASE tool whose components adhere to their meta-model. Figure 10 (Glorio & Trujillo, 2009) shows the logical models of a sale SDW according to the proposal due to Glorio & Trujillo (2008; 2009). As shown in Figure 10, the SDW schema mixes DW modeling concepts with OLAP data cube ones and it does not provide support for the following DW modeling techniques: role-playing dimensions and bridge tables. Also, it is not possible to define whether the geometry of spatial attributes can be normalized and/or shared. As a consequence, similarly to the other two meta-model proposals due (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) (Section 4) and Malinowski & Zimányi (2007; 2009) (Section 5), the meta-model by Glorio & Trujillo (2008; 2009) does not allow a full modeling of the homicide SDW of the running example (see Section 3).

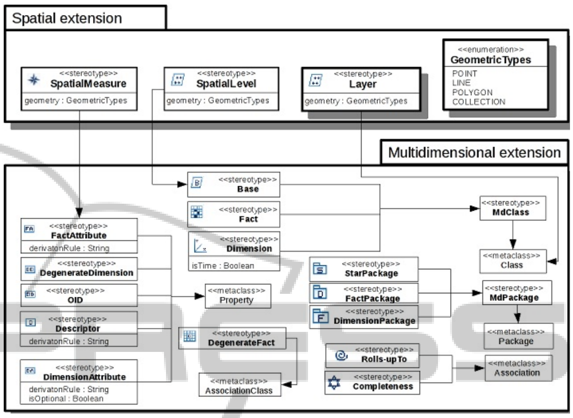

Figure 9: SDW-aware UML profile by (Glorio & Trujillo, 2008).

Looking again to Figure 10, we observe that the sale SDW schema modeled according to the methodology by Glorio & Trujillo (2008; 2009) exposes one fact table, called *Sales*, which is characterized by conventional measures only (e.g., *cost* and *total*) and three dimensions: *Store*, *Product* and *Client*, equipped with levels having conventional and spatial attributes (e.g., *category* and *geometry_polygon*). This means, again, mixing concepts from different contexts (i.e., DW and OLAP). Also, similarly to the previous meta-models investigated in our analysis, the solution by Glorio & Trujillo (2008; 2009) does not provide a concise and compact notation. In fact, again one class (it should be reminded that in this case UML extensions are considered) is introduced for each dimensional level.

Figure 11 shows the sale SDW of Figure 10 modeled by means of SDWCASE according to SDWM. Again, the two schemas are equivalent. Similarly to the case of the highway SDW (see Section 5), in the logical model of the sale SDW according to SDWCASE of Figure 11, we simply define all geometries as not normalized and not shared, hence again obtaining redundancy, high data volumes and difficult SDW administration. Just like the previous case, we observe that, contrary to this, the SDWM meta-model offers a more concise and compact solution (five dimensions in the SDWM's case – see Figure 11 – vs eight dimensions in the

Glorio & Trujillo's (2008; 2009) case – see Figure 10).

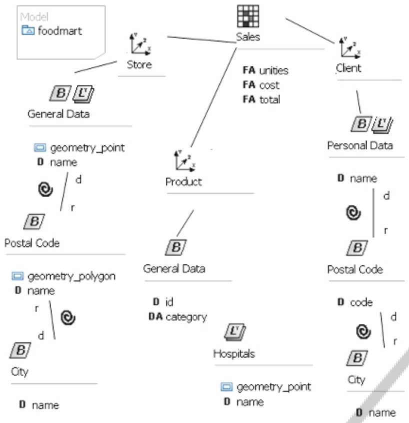

Figure 10: Sale SDW according to (Glorio & Trujillo, (2008).

Summarizing, from the results of this analysis we can conclude that, with respect to the meta-model proposed by Glorio & Trujillo (2008; 2009), the proposed meta-model SDWM exposes a clearly-higher expressive power, along with more concise and compact schemas, according to similar consideration given in Section 4 and Section 5.

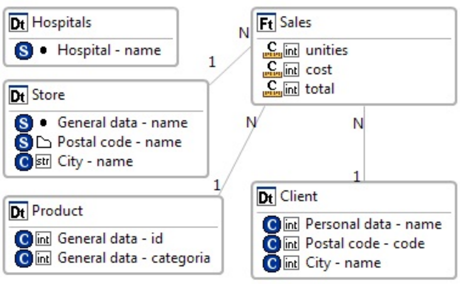

Figure 11: Sale SDW according to SDWM.

7 COMPARATIVE ANALYSIS RESULTS

In this Section, we provide the results of the comparative analysis on the proposed meta-model SDWM against the related ones we discussed in the previous Sections.

Table 1 summarizes the results of our analysis. As it follows from Table 1, all comparison approaches allow us to design spatial measures. However, no proposal except the SDWM one addresses spatial attributes. As a consequence, comparison approaches do not support determining whether the geometry of a spatial attribute should be normalized and/or shared among different dimensions. As highlighted in previous Sections, it should be recalled here that normalizing and sharing spatial attributes has the beneficial effect of reducing the whole data volume of SDW and making the SDW administration simpler.

Moreover, among comparison approaches, only the proposal by (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) (*i*) disassociates DW modeling concepts from OLAP data cubes modeling concepts, and (*ii*) addresses the degenerated dimension modeling technique. Unfortunately, for what regards bridge tables and role-playing dimensions, no comparison approach addresses these yet-useful constructs.

Also, contrary to the SDWM approach, where we make use of suitable spatial attributes to represent spatial information, (Fidalgo et al., 2004; Times et al., 2009; da Silva et al., 2010) model spatial information as dimensions, Malinowski & Zimányi (2007; 2009) as ER entities, and Glorio & Trujillo (2008; 2009) as UML classes.

Finally, as highlighted throughout the paper, comparison approaches are clearly not capable of providing concise and compact SDW schemas like the SDWM approach.

Table 1: Results of the comparative analysis among SDW meta-modeling approaches.

	(Fidalgo et al., 2004)	(Malinowski & Zimányi, 2007)	(Glorio & Trujillo, 2008)	SDWM
DW vs OLAP Modeling	YES	NO	NO	YES
CASE Tool	YES	NO	YES	YES
Degenerated Dimensions	YES	NO	YES	YES
M-N Relationships (Bridge Tables)	NO	NO	NO	YES
Role-Playing Dimensions	NO	NO	NO	YES
Spatial Attributes	NO	NO	NO	YES
Spatial Measures	YES	YES	YES	YES
Concise Notation	NO	NO	NO	YES
Normalized Geometry.	NO	NO	NO	YES
Shared Geometry.	NO	NO	NO	YES
Yes (%)	40	10	30	100
NO (%)	60	90	70	0

8 CONCLUSIONS AND FUTURE WORK

In this paper, we have provided a comparative analysis of the SDWM approach (Del Aguila et al., 2011; Cuzzocrea & Fidalgo, 2012a; Cuzzocrea & Fidalgo, 2012b) against the state-of-the-art SDW meta-model proposals (Fidalgo et al., 2004; Malinowski & Zimányi, 2007; Glorio & Trujillo, 2008). Results of our analysis clearly state that the SDWM proposal exposes a higher expressive power and allows us to obtain more concise and compact SDW schemas.

Future work is oriented towards enriching SDWM with novel aspects such as *security and privacy of SDW*, in line with recent results in the context of security and privacy of DW and OLAP (e.g., (Cuzzocrea & Bertino, 2011; Cuzzocrea et al., 2012; Cuzzocrea & Saccà, 2012)).

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