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An efficient framework for spatiotemporal 4D monitoring and management of real property

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Introduction

- 3D land information systems advantages than the conventional 2D systems
  - Boarder range of information
  - They permit the spatial extent of ownership boundaries, & registering related property rights in all dimensions.
  - 3D cadastral data models valuable in urban development, utility networks or transportation projects.
  - Building 3D models are basically created <u>by photogrammetric techniques</u> including airborne and close range photogrammetry.
  - Those models can then be linked to 3D city information models such as CityGML so as to cover a vast range of metadata regarding a particular real estate asset.

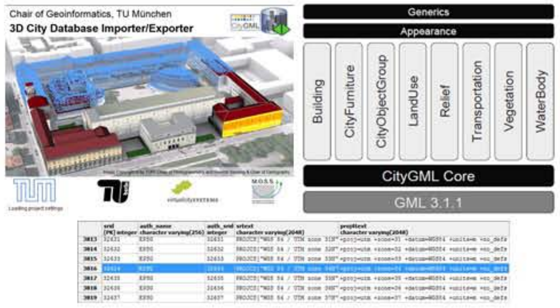
Temporal Variability:**4D Modelling**

- Through Time existing buildings may undergo changes in their facades, roofs, height, use, etc.
- New buildings
- Significant Renovation, etc.
- Land information at **4 Dimensions**: **3D Geometry Plus Time.**

- *However, repeating the 3D modeling and information acquisition and capturing processes on a periodical (say, e.g., annual) basis is an unrealistic and practically impossible goal, because of the prohibitive amount of computational, financial and other resources (time, labour, expertise, equipment, etc.) needed. Therefore, a more efficient framework for 4D monitoring of real property is essential.*

Overview of our Approach

Terrestrial lidar, close range and airborne imagery



Real property metadata

Aerial and/or terrestrial images, possibly "in the wild" images

Precise 3D model
Sophisticated photogrammetry techniques (point cloud geo-referencing, geometric reconstruction, texture mapping, ...)

CityGML data model
PostgreSQL / PostGIS (info on function, usage, owner, rights, etc.)

Approximate 3D model
via simpler, cost-effective techniques

4D modeling
Change History Maps, change region detection, partial reconstruction & 4D land information system update

3D MODELING OF REAL PROPERTY

- Creating a precise 3D model of a building requires obtaining and combining a dense point cloud, texture mapping and geo-referencing information of the building under reconstruction effected via sophisticated laser scanning and photogrammetry techniques.

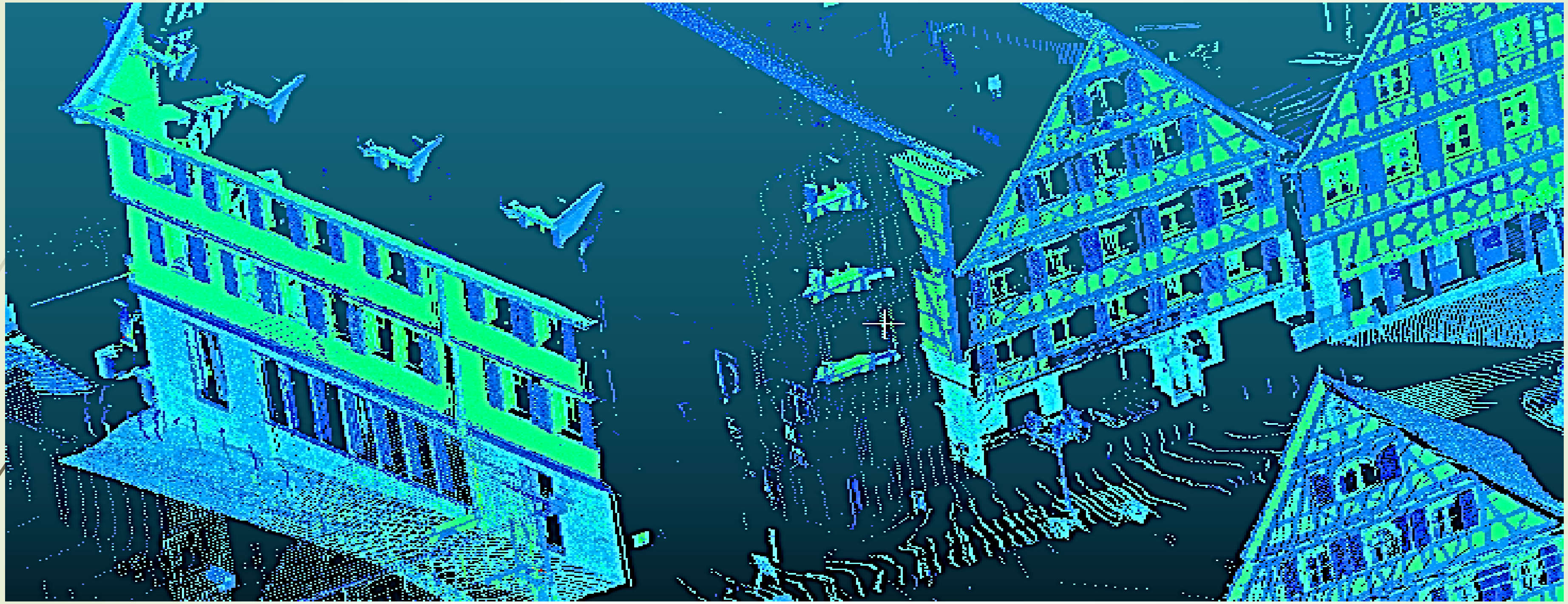
Historic Market Square of Calw in Germany

- *3D photorealistic models of outdoors objects by means of automatically georeferenced High Definition Surveying (HDS) point clouds and still video images. The latter are used to both detect point features which are also found in the 3D HDS point cloud, and, to serve for photorealistic 3D models too.*

Data acquisition, image registration and post-processing

- Terrestrial LiDAR -reliable measurement environment and efficiency.
- However they sometimes prevent us from having a complete perspective of the buildings' facades.
- Combining static LiDAR with other systems, such as close range and airborne photogrammetry, can offer a significant advantage.
- An integrated GPS/INS system aboard is used for directly georeferencing the images, thus the local point cloud can be automatically georeferenced.

An example- Occlusion Problems



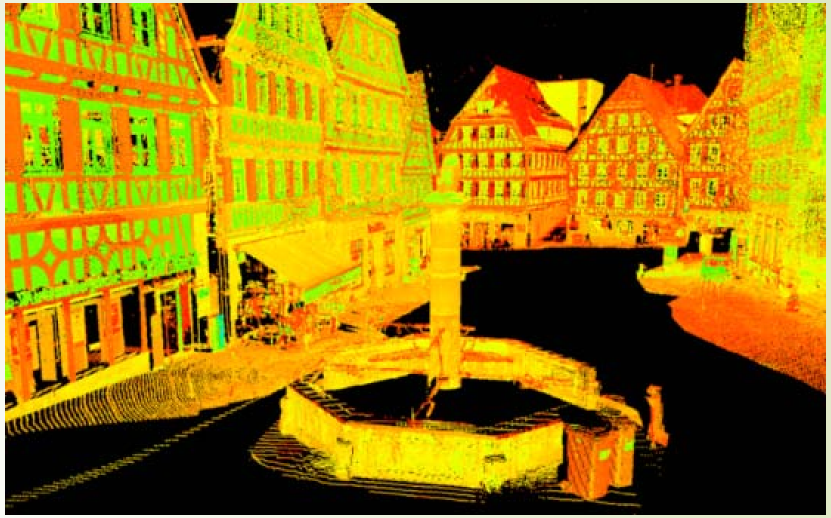
Occlusion-type errors in terrestrial laser scanning

Data Collection

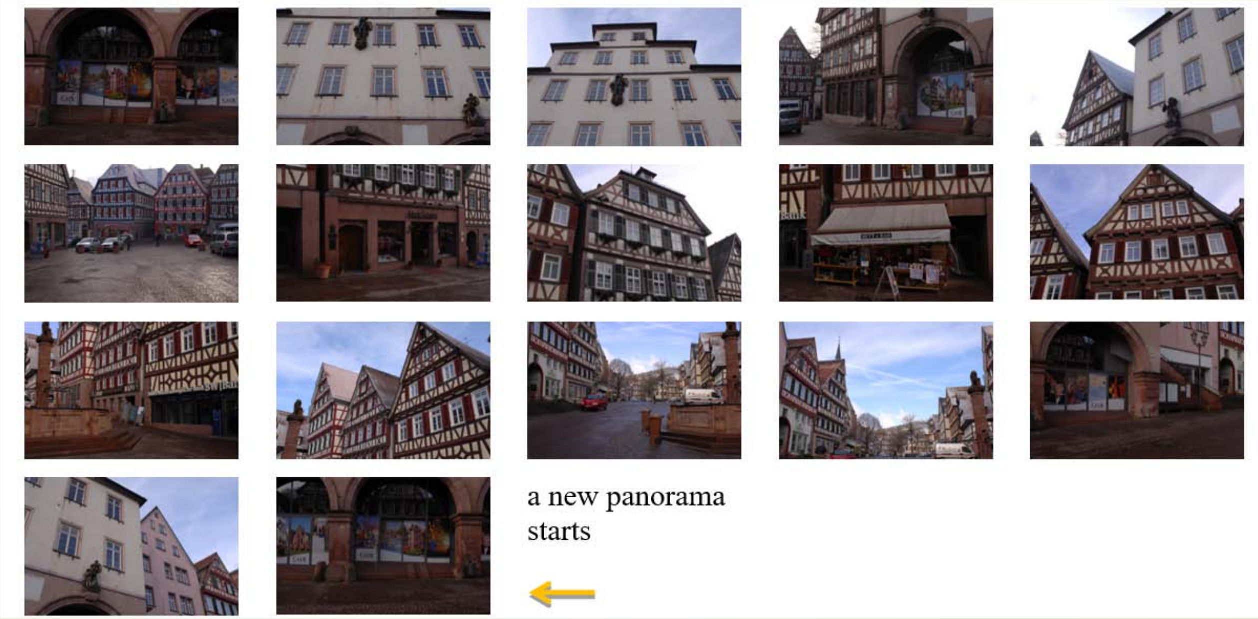
Terrestrial laser scanning data: To begin with, point clouds can be collected using a laser scanner such as the Leica HDS3000 TLS.

Close range photogrammetric image data: Digital photogrammetric image data pertain to both close range (facades) and airborne photogrammetry.

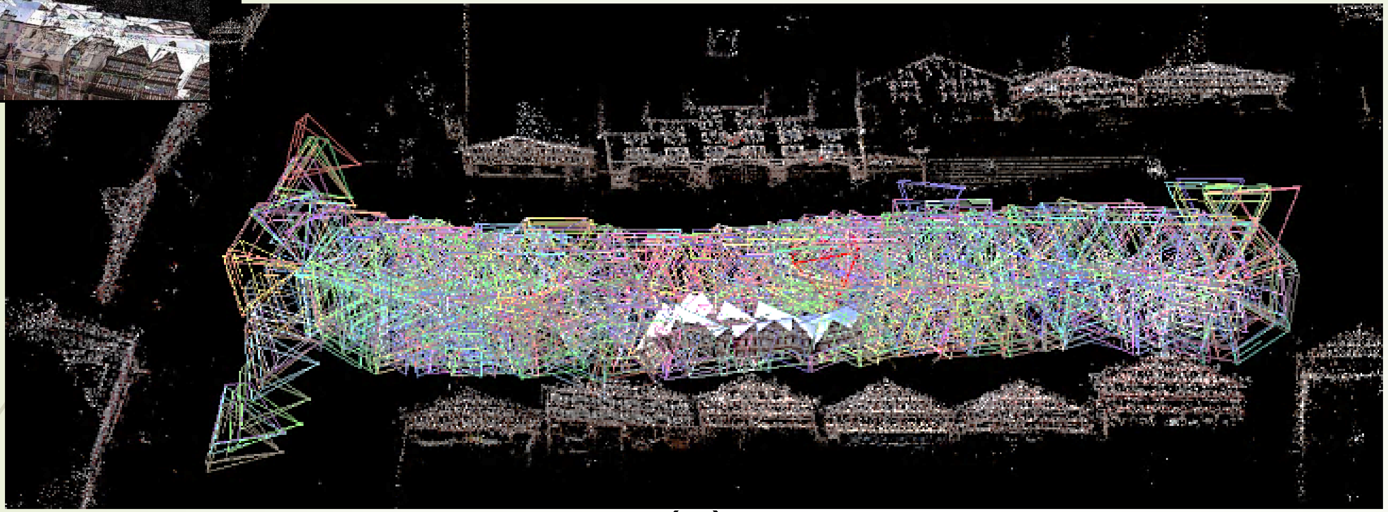
We use **One Panorama Each Step"**



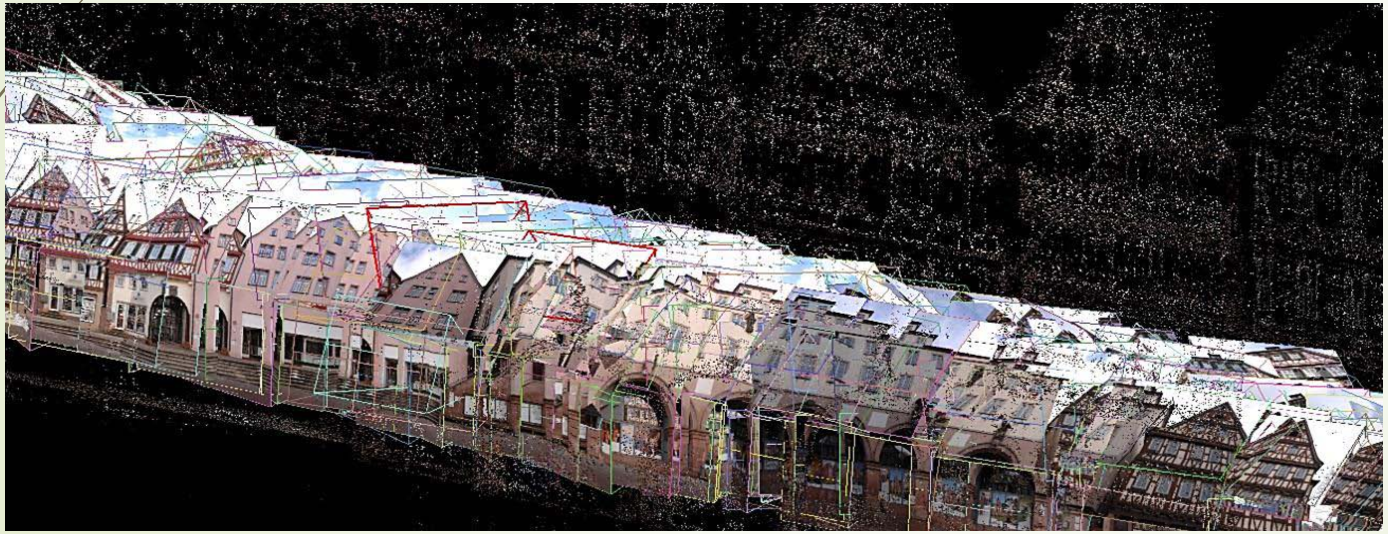
(a) Calw Market Square, Lower Part, (b) Point Cloud



One Panorama Each Step" Acquisition Strategy



(a)

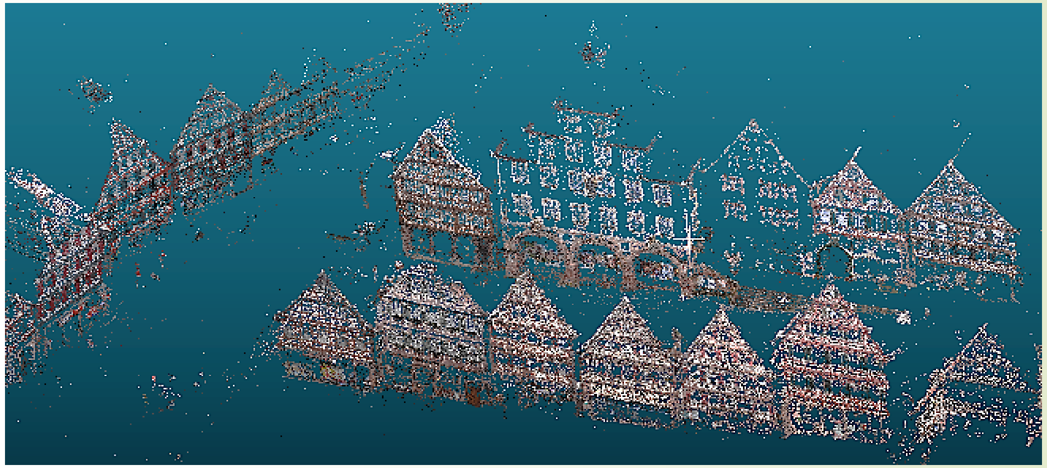


(b)

“One Panorama Each Step” Acquisition Strategy.
Left: A Sequence. Right: 80% overlap in each step.

Image Registration

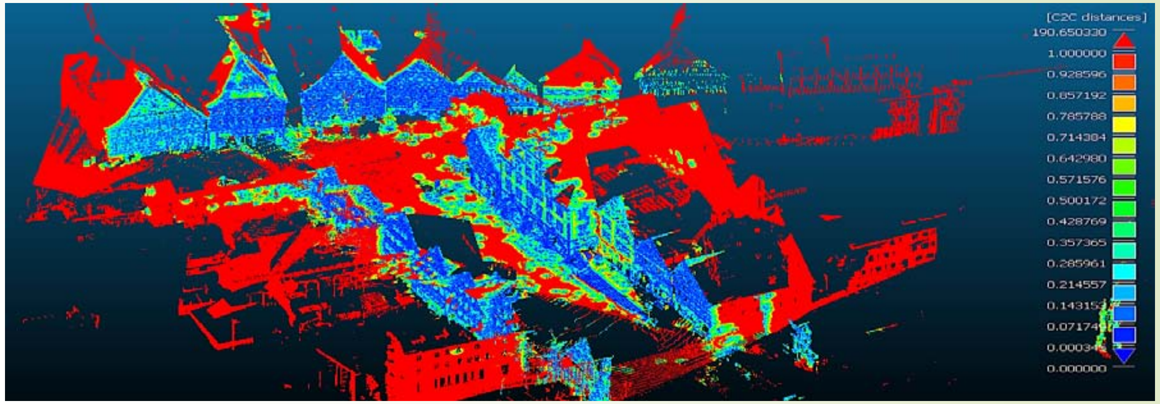
- **Automatic**
  - Robust pairwise feature extraction and matching from all digital images and the generated laser RGB image
  - Data transformation from model to object space after parameter estimation using detected control points from the previous two steps.



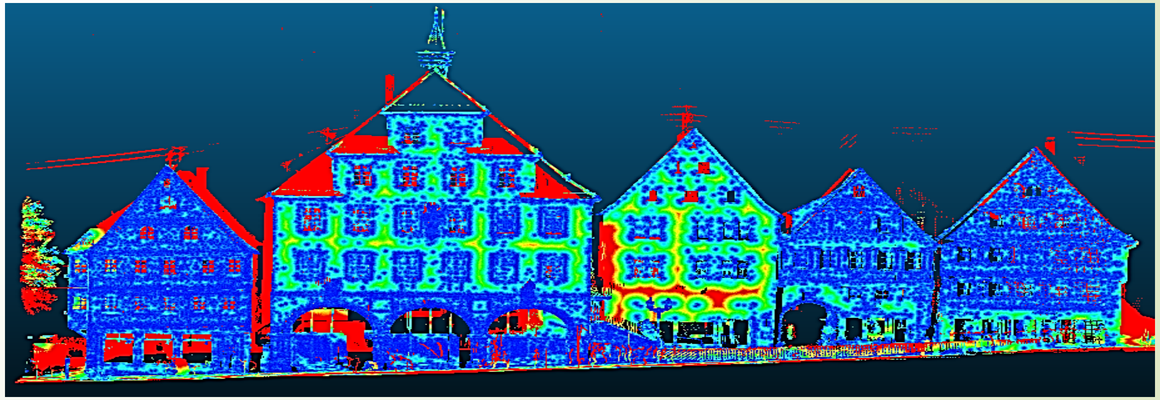
Sparse 3D Reconstruction of Main Facades in Model Space

Visualization of the Registration

- The registration is visualized using a cloud to cloud distances scalar field, with the registered cloud as the reference.
- This method computes the distance from each laser point to its closest point from the registered cloud



(a)



(b)

(a)Cloud to cloud distances scalar field, (b) Bottom: Map of target areas

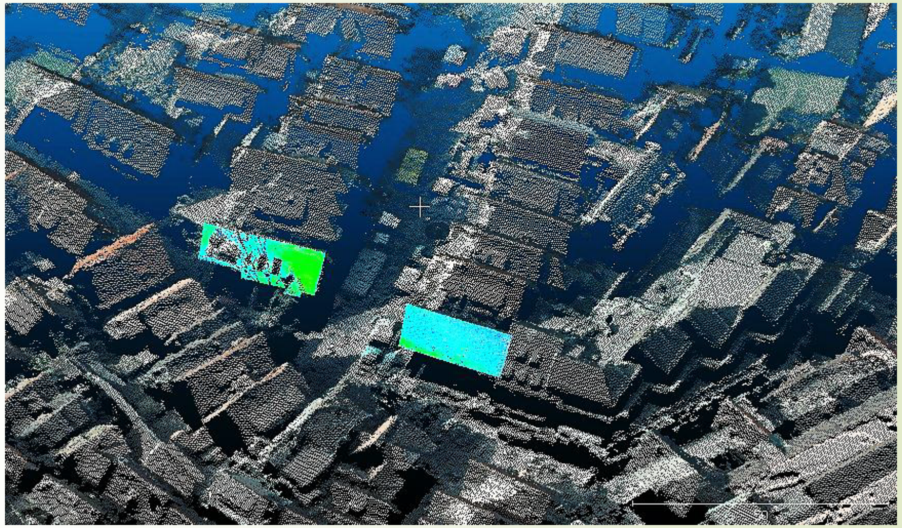
Registration Method-2

- Using **Iterative Closest Point Algorithm (ICP)**, which requires the clouds to be already coarsely aligned to each other manually.
- The ICP algorithm then refines the registration by minimizing the distances between the corresponding point clouds
- The resulting Exterior Orientation and calibration parameters from the Bundle Adjustment are used for Dense Image Matching, based on the Semi-Global Matching strategy implemented in the SURE software **[from our collaboration with Un. Of Stuttgart]**
- This step is necessary to register the dense imagery point cloud with the laser point cloud with the objective of correcting occlusions in the building facades

Very dense 3D reconstruction using Absolute Oriented Images

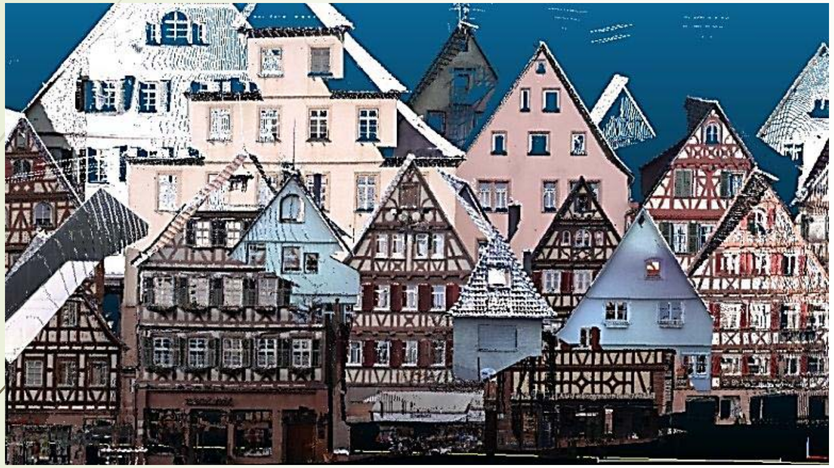
Georeferencing

- Terrestrial Laser Scanning is fast and efficient and delivers point clouds of superior quality **but suffers from occlusions, especially in inclined viewing directions.**
- Close range photogrammetry covers panoramas and delivers very dense point clouds of excellent quality **but suffers from lack of information for the roofs.**
- Therefore, **airborne imagery is used**
- **Our Method:** In the described developments a total of 6 images with 10cm ground sampling resolution (GSD) have been processed. With the already oriented aerial photographs georeferenced point clouds in Gauss-Krüger coordinates are obtained. A follow-up semi-automatic registration via the ICP algorithm is used for georeferencing all available point clouds
- Finally, data acquisition and point cloud alignment using **post-processing steps.**
  - Occlusions in the laser data can be corrected using close range photogrammetry and missing visual information from roofs is provided by the airborne data.
  - Enhancement of the color of the laser point cloud. The laser color might contrast with that from the digital camera system. I
  - We project the TLS point cloud into the absolutely oriented close range imagery.

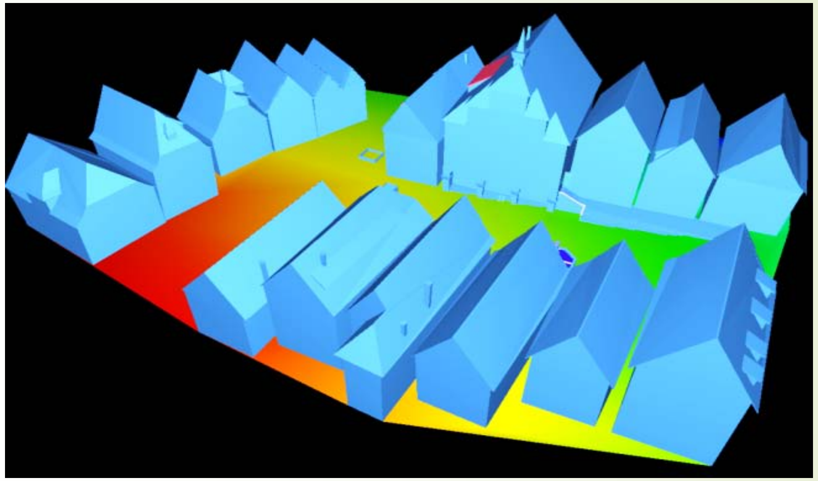


Automatic reconstruction of Point Clouds of the roof landscapes using airborne photographs. In green the types of region from the TLS Point Clouds for georeferencing via ICP

3D modeling of real property



(a)



(b)

3D Model of Calw Market Square **without texture**.

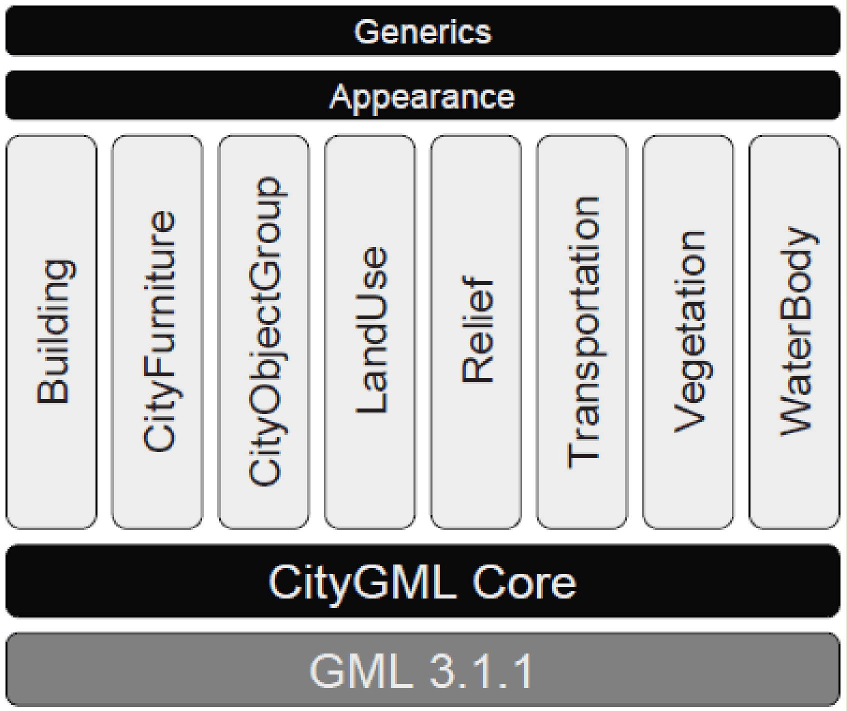
Texture Mapping

Perspective effect in texture mapping

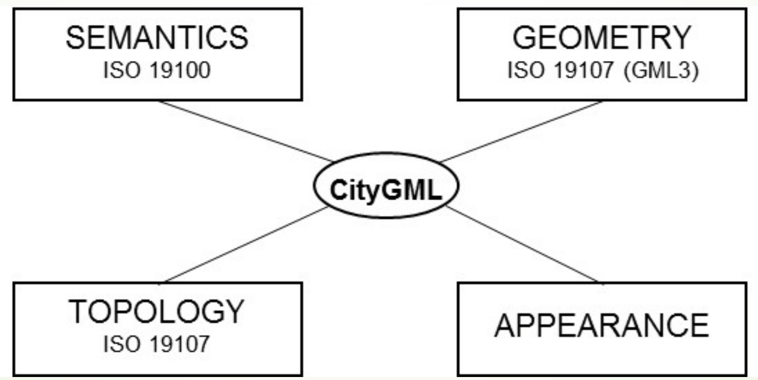
CITYGML FOR REAL PROPERTY METADATA

- CityGML is an open data model for the storage and exchange of virtual 3D models of cities and landscapes.
- This standard is based on the Geography Markup Language 3 (GML3) schema (XML format) issued by the Open Geospatial Consortium (OGC) and ISO TC211.
- CityGML covers the geometrical, topological, semantic and appearance aspects of 3D city models.
- Furthermore, it differentiates between five consecutive Levels of Detail (LoD).
- All spatial objects can be represented by five different LoDs, from LoD0 to LoD4, ranging from simple shells to finely detailed models.
- A CityGML model is accompanied by an object-relational geospatial database (PostgreSQL w/ PostGIS 2.0 extension) and the schema of the database is structured in the format of the 3D City Database (3DCityDB).
- 3DCityDB is a geo database that allows for storage, management and representation of 3D city (CityGML) models of each LoD.
- This schema includes 60 tables, which are related to the Coordinate Reference System (CRS), the landscape, the buildings and the city objects of the study area. It's an extendable schema that also enables the inclusion of proprietorial information and building restrictions.

CityGML application Fields



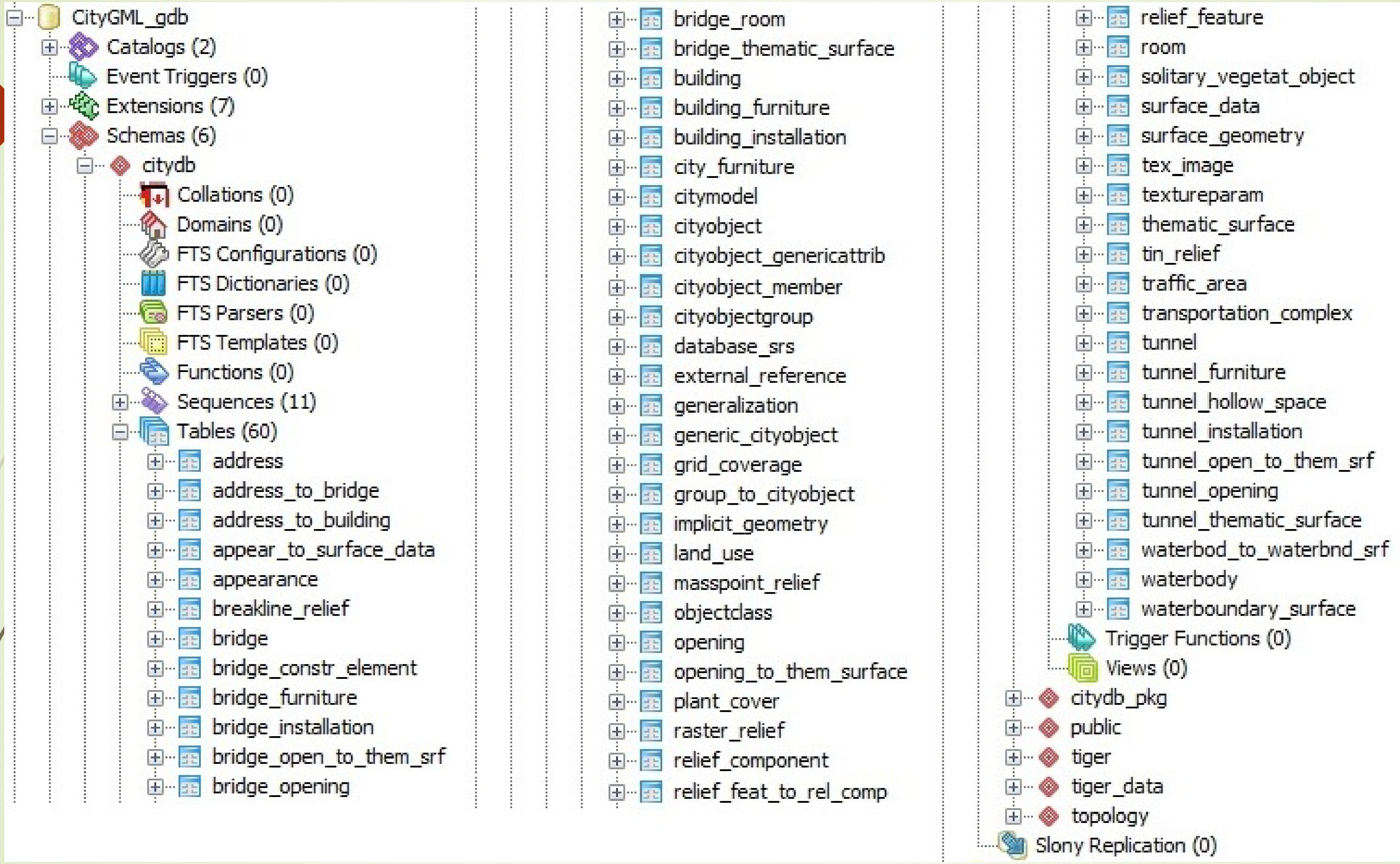
CityGML Structure



Application Components

Our CityGML Model

- We develop a database in PostgreSQL/PostGIS
- We connect this database to 3DCityDB package to get structured according to the 3DCityDB/CityGML schema and define the CRS
- The existing 3D model is also connected to the structured database within the 3DCityDB.
- The database is populated with the appropriate spatial data, like the geometrical envelope and the topological relations, of all the objects' parts of the connected 3D city model
- The data types represents elements of buildings' function, usage, year of construction or demolition, roof type, height, storeys above and below ground, address, rooms and furniture, proprietorial information, like owner, rights, obligations and building restrictions, like built-surface ratio, type of coverage, allowable building area and height, as well as information about the land use, the vegetation and waterbodies, other city objects and their surfaces and textures.
- The updated database is connected again to the 3DCityDB. I


CityGML_gdb
Catalogs (2)
Event Triggers (0)
Extensions (7)
Schemas (6)
citydb
Collations (0)
Domains (0)
FTS Configurations (0)
FTS Dictionaries (0)
FTS Parsers (0)
FTS Templates (0)
Functions (0)
Sequences (11)
Tables (60)
address
address_to_bridge
address_to_building
appear_to_surface_data
appearance
breakline_relief
bridge
bridge_constr_element
bridge_furniture
bridge_installation
bridge_open_to_them_srf
bridge_opening
bridge_room
bridge_thematic_surface
building
building_furniture
building_installation
city_furniture
citymodel
cityobject
cityobject_genericattrib
cityobject_member
cityobjectgroup
database_srs
external_reference
generalization
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grid_coverage
group_to_cityobject
implicit_geometry
land_use
masspoint_relief
objectclass
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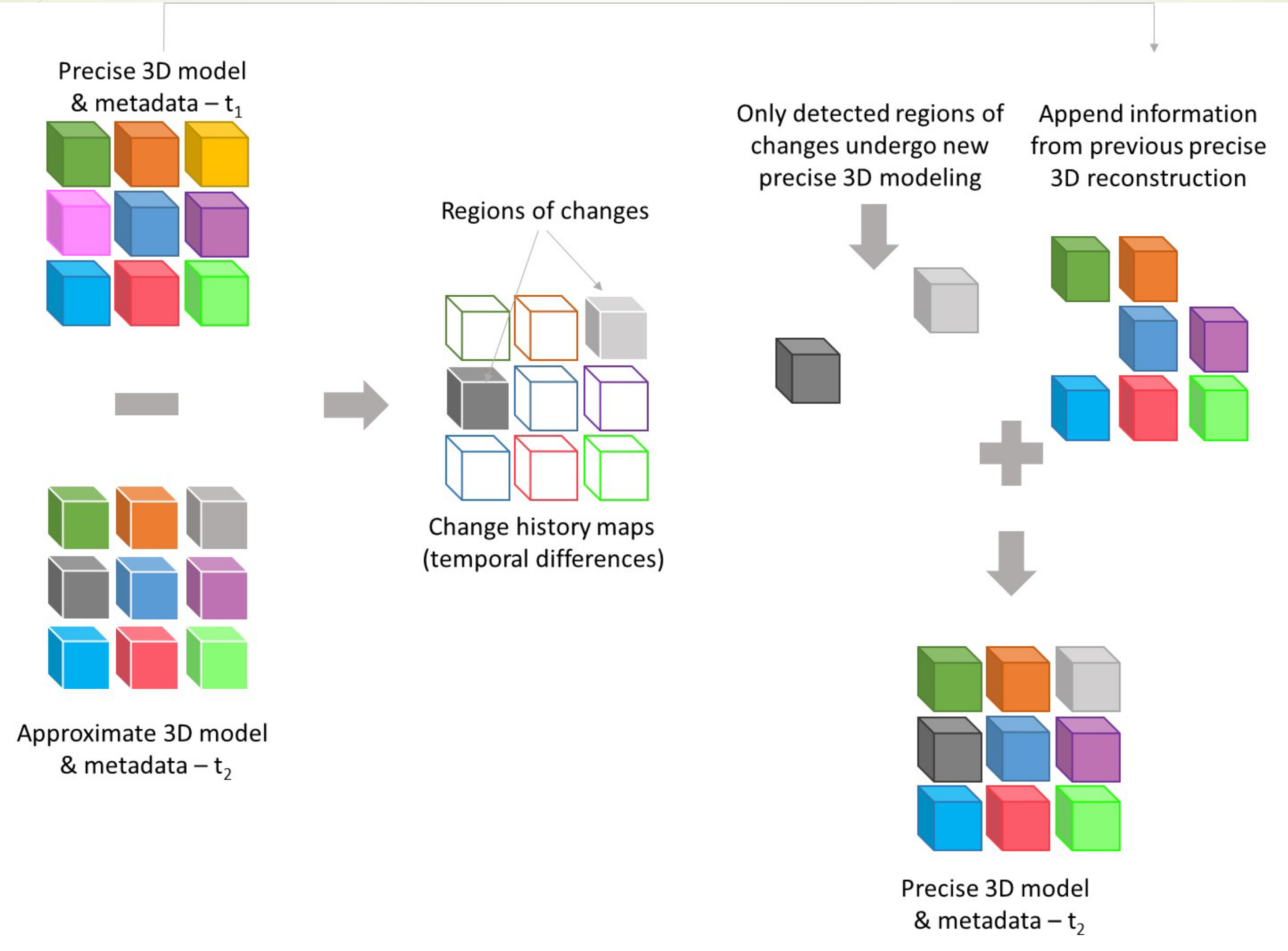
opening_to_them_surface
plant_cover
raster_relief
relief_component
relief_feat_to_rel_comp
relief_feature
room
solitary_vegetat_object
surface_data
surface_geometry
tex_image
textureparam
thematic_surface
tin_relief
traffic_area
transportation_complex
tunnel
tunnel_furniture
tunnel_hollow_space
tunnel_installation
tunnel_open_to_them_srf
tunnel_opening
tunnel_thematic_surface
waterbod_to_waterbnd_srf
waterbody
waterboundary_surface
Trigger Functions (0)
Views (0)
citydb_pkg
public
tiger
tiger_data
topology
Slony Replication (0)

Our Scheme Properties

- The final files that are exported by 3DCityDB are a CityGML file in GML3 format, which includes spatial and descriptive data from the database and KML/COLLADA files that allow for visualization in Google Earth environment.
- KML/COLLADA files are also enriched with information by the relational database and visualize all the objects of the 3D city model in several types: **their footprint on the ground, their volume, the analytical geometry of their surfaces and the different colors per type of surface, their surfaces' textures.**
- **A pop-up balloon appears** next to it with some information about it from the database.
- This procedure facilitates engineers who operate within the urban planning, the land management, registry and other relevant fields, offering data organization.
- It also supports SQL and thus allows for analysis tasks, complex queries on the database, data and schema validation and spatial data management and mining through the PostGIS extension.

CHANGE HISTORY MAPS: AN EFFICIENT APPROACH TO 4D MONITORING



4D Maps Description

- Ideally, being able to produce 3D modeling results of real property for different time periods would lead to a **consistent 4D "reconstruction".**
  - **A large amount of resources (equipment, man effort, time, etc.) making the process an expensive (both computationally and financially), arduous and practically impossible task.**
- **Change history maps detect regions of interest in the 3D space** by combining multiple instances of a 3D model.
  - The change history map determines the regions that need to be reconstructed more precisely than others due to temporal changes.
- Geometric differences of the 3D models.
- Due to noise, we initially smooth the 3D models by the application of a Gaussian pyramid filter. Then, change history maps are created directly from the filtered 3D models.
- The ICP algorithm is used for alignment among different periods.

Conclusions

- Real property monitoring and management can reap significant benefits by the progress of 3D modeling techniques as well as the continuous improvement of open data models pertaining to urban development and real estate.
- 4D cadastral and land information systems to capture the changes buildings undergo in the course of time
- We levegage 3D information from previous photogrammetry-based modeling instances to create 3D models of real property for new time points focusing only on those cases and regions where changes have occurred.
- The proposed efficient framework is enabled by the Change History Maps concept which also covers potential changes in semantic metadata of real property, as documented in PostgreSQL databases using the CityGML model

Thank You!