# BUILDING HEIGHT RETRIEVAL IN URBAN AREAS IN THE FRAMEWORK OF HIGH RESOLUTION OPTICAL AND SAR DATA FUSION

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## 1. INTRODUCTION

During the last years, new approaches, exploring the high detail level characterizing high-resolution optical and SAR images provided by current spaceborne sensors, have been proposed for object detection and reconstruction in urban areas. Especially, challenges are born in the fields of building extraction and building height estimation for 3D reconstruction of urban scenes.

Some technics such as stereoscopy [1], radargrammetry [2] [3] and interferommetry [4] [5] or simulation-based methods [6], have been applied to deal with this problematic and have given satisfying results of building extraction and height estimation.

Nevertheless, some difficulties can be still pointed out: optical couple availability, need of auxiliary input data, incomplete or noisy results from SAR images...

In this context, news methods have been recently developed in the frame of optical - SAR data fusion, that focus, most of the time, independently on different individual aspects or subparts of the 3D building reconstruction, such as the building boundary detection [7] [8] [9] and the height estimation from one single SAR image [10] or from a couple of interferometric SAR images [11].

We propose, in this paper, a complete and semi-automatic processing chain, able to provide the simple 3D reconstruction of buildings in large urban scenes. The process takes only as input one HR optical image and one HR SAR image of the same area and tends to fully exploit complementary information provided by proper building features in both data. A simple parallelepipedic building model is used for the reconstruction. The chain is decomposed into the two main steps: In a first step, a new scheme for building footprint extraction based on the combination of optical and SAR features is developed and allows us to obtain a robust building detection, ensured by an optical - SAR crossed validation. In a second step, a process for building height estimation from SAR data, developed in our previous works [12], is briefly reminded and a new approach for building presence validation, taking into account confidence scores computed during both steps, is proposed. Finally, the 3D reconstruction of a studied urban scene of interest is achieved by using information obtained throughout the chain about building location, height estimation and presence validation, and is illustrated on a couple of Quickbird and TerraSAR-X images in the area of Marseille (France).

## 2. BUILDING DETECTION BASED ON OPTICAL AND SAR FEATURES

The first step of the processing chain aims to extract rectangular building boundaries from the couple of optical and SAR images without other auxiliary input data.

### 2.1. Presentation of the building detection scheme.

A new symetric building detection scheme, based on the combination of optical and SAR information is developed and allows us to deal with complex urban scenes with metric resolution, characterized by various, complex and variable building features.

Indeed, in high resolution optical or SAR imagery, buildings may appear very differently, according to a lot of parameters (sensor incidence, building material and complexity, roof slope, disturbing neighbourhood, ...). Consequently, features composing building signatures, that are representative of building presence, may be more or less easily identified on real data. For instance, on optical images, building boundaries appearing with an important background / object border contrast, may be more or less clearly imaged; while, on the corresponding SAR images, characteristic building features such as double echoes from ground / wall corners, layover areas, textured roof areas and shadow areas, may be easily visible or not.

In order to cope with this high building signature variability, we propose a symetric scheme for robust building detection, based on an optical - SAR crossed validation, that allows us to ensure building presence or absence and to fully exploit complementary information provided by both building features, in the data fusion framework.

The principle is the following: In a first time, two sets of rectangular windows of interest, defined as rectangular areas likely to contain buildings with a high probability, are independently identified on the optical image and on the SAR image, by using proper characteristic building features. Both sets of rectangular windows of interest are then merged together into a global ”window map”. In a second time, a local refinement process, aiming to precisely extract buiding footprint boundaries is performed on the optical thresholded gradient image, around each window of interest provided by the ”window map”.

### 2.2. Phase 1: Identification of windows of interest on optical and SAR data.

On the optical data, the set of rectangular windows of interest, is identified by using the combination of morphological and geometrical tools. As described in [8], the Differential Morphological Profile (DMP) [13] of the optical image is first built, by using operators by reconstruction, to provide a progressive simplification of the scene at different scales. Then, a geometrical criterion, refering to the adequation of a considered area with a reference surface, is hierarchically tested on the different objects present on each image in the DMP and provides likely building windows.

On the SAR data, the set of rectangular windows of interest is symetrically identified by using the presence of characteristic building features, previously extracted on the SAR image (bright lines issued from double bounce reflexions and shadow areas).

Windows of interest issued from the SAR data are projected into the optical image referential by using the available optical and SAR models of projection and an approximate height information provided by a coarse Digital Terrain Model (DTM).

Both sets of windows are then merged together into a global ”window map”, which will allow us to directly focus on candidate building areas with high potential.

### 2.3. Phase 2: Building footprint extraction on the optical image.

Finally, a contour-based approach is processed around each area provided by the ”window map”. This one determines the optimal rectangular building footprint that can be generated from the main local direction into the extended window bounding box, and that minimizes an energetic cost computed on the optical thresholded gradient image.

The output is a fined binary map, called ”boundary map”, identifying precisely building location in the optical planimetric referential.

A first score of confidence, taking into account the energetic cost value and the fact to be or not ”crossed validated” (when belonging simultaneously to the optical and SAR window set), is available for each detected building of the ”boundary map”.

### 2.4. Application on real images and evaluation of the performances.

The complete building detection process is applied on a studied urban scene, imaged on a couple of high-resolution Quickbird and TerraSAR-X images (respective resolution of 0.6 meters and 1.1 meters) in the area of Marseille in France.

The results obtained are quantitatively qualified by computing the detection rate, the false alarm rate, and the misclassified pixel rate.

It is shown that the introduction of such an optical - SAR crossed process permits to give relevant and very satisfying building detection results.

## 3. BUILDING VALIDATION AND HEIGHT RETRIEVAL FOR 3D RECONSTRUCTION

The second step of the processig chain aims two objectives: firstly, strengthening building presence hypothesis to deliver a map of validated buildings, and, secondly, providing, for each building previously extracted on the optical image, a height information issued from SAR data, in the perspective of the 3D scene reconstruction.

### 3.1. Presentation of the building validation and height retrieval scheme.

The principle is the following: In a first time, a phase of projection and registration beetween homologous building features has to be performed, in order to combine two kinds of information issued from both images, i.e. a planimetric information from the optical data and an altimetric information from the SAR data. In a second time, the proper phase of building height retrieval, based on the optimization of a statistic criterion, depending on the building height and computed on the SAR image, is applied in order to get relevant estimations of the individual building heights. In a third time, the phase of building presence validation is achieved by integrating clues accumulated during both global steps of the processing chain. In a last time, the final phase of 3D reconstruction of the studied scene is realized by assembling information obtained throughout the chain, about building location, height estimation and presence validation.

### 3.2. Phase 1: Building footprint projection and registration on the SAR image.

We are led to project the rectangular optical footprints into the SAR image and to match them with their homologous SAR features, i.e. with the bright linear echoes coming from the double bounce ground / wall reflexions.

The original method of projection and registration refinement, presented in [8], has been applied on the studied scene and can be decomposed in two parts: First, the building boundary projection is applied by using the available physical parametric joint model of projection. Then, the ground feature registration refinement is performed by using a radiometric mean criterion computed on the SAR image.

We obtain at the end a fine adjustement of the projected footprint location on ground in the SAR image.

### 3.3. Phase 2: Building height estimation from SAR data.

As described in [12], the strategy employed for height retrieval is based on the global scheme of: "Height Hypothesis - Test Partitioning Generation on SAR Data - Statistical Criterion Optimization".

In a first place, we define, for each optical potential building footprint, projected and registered into SAR data, an individual building subcene, likely to contain all potential characteristic SAR areas of the building signature ("double echo area", "layover area", "single roof area", "shadow area" and "background area").

In a second place, the optimization scheme is iteratively performed: A height test value is first chosen; a potential partitioning of the subscene into the different characteristic areas is then computed in function of the height test value, of the footprint location and dimensions and in function of some known SAR acquisition parameters; finally, a statistical criterion - the global Log-Likelihood - is computed on the test partitioning, by using SAR intensity of pixels belonging to the different areas and under the classical assumption that the intensity distribution of each area can be modeled by a Gamma density function.

At the end, the height test value leading to a maximal Likelihood criterion, which correponds to an optimal geometric adequation between the predicted partitioning and the real signature, is used to estimate the most reliable building height.

The output, called the "height map", will be used in the following to provide an altimetric information for each building.

### 3.4. Phase 3: Building validation.

We try here to get the confirmation of building presence by mixing all clues accumulated throughout the processing chain.

A second score of confidence is computed by taking into account the estimated building height value and by analyzing the curve representating the evolution of the statistic criterion in function of the height, and more particularly, the shape of the curve peak, that can be or not quantitatively specified as a representative peak.

A global confidence score is then calculated by fusing both previous scores.

The decision about building presence validation is finally taken by thresholding on the global confidence score and a "validated building map" is thus obtained.

### 3.5. Phase 4: Simple 3D reconstruction of an urban scene.

Under the assumption of a simple 3D parallelepipedic building model, the 3D reconstruction of the urban scene can be easily realized by combining the planimetric location information issued from the "boundary map", the altimetric information issued from the "height map" and the building presence information issued from the "validated building map".

### 3.6. Application on real images and evaluation of the performances.

The complete building validation and height estimation process is applied on the whole studied urban scene.

The obtained results are qualified in terms of height estimation precision by comparison with reference values deduced from ground truth photographies.

It is shown that a satisfying 3D reconstruction of the whole urban scene can be achieved at the end of the developed processing chain.

## 4. CONCLUSION AND FURTHER WORKS

A complete and operational processing chain, able to produce a relevant 3D reconstruction of urban areas from a couple of optical and SAR data with metric resolution, has been developed and illustrated on Quickbird and TerraSAR-X images.

It has been demonstrated that the new scheme, proposed for the phase of building detection and based on optical and SAR features, could provide precise, robust and complete results for building boundary extraction. The phase of building validation, using the crossed combination of optical and SAR clues for building identification, as well as the phase of height estimation, founded on the optimization of a statistic criterion, have proved to give satisfying and reliable results.

In future work, the complete methodology could be extend to more sophisticated buildings. An other interesting aspect would be to generalize the approach when an additional interferometric height information is available as input.

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