INTISARI

Candi Borobudur merupakan candi Buddha terbesar di dunia yang telah ditetapkan sebagai salah satu situs cagar budaya dalam Daftar Warisan Dunia UNESCO Nomor 592 Tahun 1991. Dengan ditetapkannya Candi Borobudur sebagai warisan budaya dunia maka upaya pengelolaan yang tepat diperlukan untuk menjaga eksistensi Candi Borobudur. Seiring berjalannya waktu, di balik kemegahan arsitektur Candi Borobudur terdapat berbagai ancaman yang dapat membahayakan kelestariannya, antara lain potensi bencana alam, perubahan iklim, dan pariwisata dalam jumlah masif. Sebagai suatu cagar budaya yang perlu dilestarikan, aspek fisik maupun aspek historis Candi Borobudur belum terkelola secara maksimal karena sebagian besar dokumen pendukungnya masih dalam bentuk cetak yang berisiko rusak atau hilang pada saat mobilisasi data dan terjadi bencana. *Heritage building information modelling* (HBIM) dapat dimanfaatkan untuk mendukung konservasi Candi Borobudur melalui representasi digital 3D fisik tubuh candi dan penyajian informasi terkait elemen-elemennya sebagai sarana dalam manajemen aset dan pengambilan keputusan dalam kurun waktu siklus umur bangunan.

Penelitian aplikatif ini dilaksanakan di Candi Borobudur dengan area kajian pada lorong I sisi Barat. Data yang digunakan terdiri dari data *point clouds* hasil akuisisi *Terrestrial Laser Scanner* pada tahun 2018 dan data *close range photogrammetry* (CRP) berupa data foto 2D rangkaian panel relief Lalitavistara dan Awadana. Data *point clouds* digunakan untuk pendekatan dalam pemodelan geometri primitif 3D fasad tubuh candi Borobudur menggunakan perangkat lunak SketchUp Pro 2020. Data foto 2D rangkaian panel relief digunakan untuk rekonstruksi model panel relief menggunakan perangkat lunak Agisoft Metashape Pro. Hasil model 3D fasad tubuh candi pada *Level of Detail* (LOD) 3 dan model 3D panel relief pada LOD 4 digabungkan untuk menghasilkan model 3D keseluruhan bangunan Candi Borobudur. Pada model 3D panel relief dilakukan penambahan atribut terkait informasi elemen-elemen pada relief tersebut. Penyematan informasi semantik berbasis *International Foundation Class* (IFC) pada model 3D panel relief dilakukan untuk keperluan interoperabilitas data, sehingga dihasilkan *Heritage Building Information Modelling* (HBIM). Uji kualitas geometri dan visual dilakukan dengan membandingkan ukuran jarak hasil model 3D dengan ukuran asli di lapangan menggunakan uji-t dan hasil dokumentasi lapangan. Uji usabilitas dilakukan untuk mengetahui kelayakan HBIM yang dihasilkan.

Hasil penelitian aplikatif berupa model 3D fasad tubuh candi pada LOD 3 dan model 3D dinding panel relief Lalitavistara dan Awadana pada LOD 4. Model 3D panel relief tersebut dilengkapi atribut berupa deskripsi rangkaian cerita terkait relief (*historical narrative*), ukuran panel relief, URL panel relief, kode panel, dan status pemantauan. HBIM yang dihasilkan telah dilengkapi dengan informasi semantik berupa *ifcwall* pada bagian model 3D dinding panel relief. Hasil uji kualitas geometri menunjukkan tidak terdapat perbedaan jarak yang signifikan antara hasil model 3D dengan hasil pengukuran lapangan berdasarkan nilai t hitung sebesar 0,707575 yang berarti tidak melebihi nilai tabel t pada derajat kepercayaan 95% yakni 2,045. Hasil uji kelayakan komponen HBIM Candi Borobudur menunjukkan persentase sebesar 85,68% dan hasil uji usabilitas menunjukkan persentase sebesar 83,7%, sehingga dapat dinyatakan bahwa HBIM Candi Borobudur sangat layak untuk diimplementasikan dalam menunjang manajemen aset dan kegiatan konservasi arsitektur warisan budaya.

Kata Kunci : *Heritage Building Information Modelling* (HBIM), Candi Borobudur, manajemen aset, *close range photogrammetry*

ABSTRACT

Borobudur Temple is the largest Buddhist temple designated as a cultural heritage site in the UNESCO World Heritage List Number 592 of 1991. With the stipulation of Borobudur Temple as a world cultural heritage, proper management efforts are needed to maintain the temple's existence. Over time, behind the Borobudur Temple architectural splendour, various threats can endanger its sustainability, including the potential for natural disasters, climate change, and massive tourism. As a cultural heritage that needs to be preserved, the physical and historical aspects of Borobudur Temple have not been managed optimally because most of the supporting documents are still in printed form, which risks being damaged or lost during disasters and data mobilization. Heritage building information modelling (HBIM) can support the conservation of Borobudur Temple through digital 3D representations of the temple's physical body and the presentation of information related to its elements as a means of asset management and decision making in the building life cycle.

This research was carried out at Borobudur Temple with the study area in the first aisle on the Westside. The data consists of point clouds data from the Terrestrial Laser Scanner acquisition in 2018 and close-range photogrammetry (CRP) data in the form of 2D photos of Lalitavistara and Awadana relief panel series. Point clouds data are used to approach the 3D primitive geometry modelling of the Borobudur temple facade using the SketchUp Pro 2020. 2D relief panel photos are used to reconstruct the 3D relief model using Agisoft Metashape Pro. The temple facade 3D model results at Level of Detail (LOD) 3 and the relief panel 3D model at LOD 4 are combined to produce a 3D model of the entire Borobudur Temple building. The relief element information attributes were added to the 3D relief model. Embedding semantic information based on International Foundation Class (IFC) in the relief panel 3D model is carried out for data interoperability purposes, resulting in Heritage Building Information Modeling (HBIM). Geometry and visual quality tests were carried out by comparing the distance measurements of the 3D model results with the original measures in the field using a t-test and the results of field documentation. A usability test was conducted to determine the feasibility of the resulting HBIM.

The research produces a 3D model of the temple's facade at LOD 3 and a 3D model of the Lalitavistara and Awadana relief panel walls at LOD 4. The 3D relief panel models are equipped with attributes in the form of a description of a series of historical relief narratives, relief panel size, relief panel URL, panel code, and monitoring status. The HBIM has been semantically equipped with an ifcwall. The geometry quality test shows no significant difference in distance between the 3D model and the field measurements based on the t-count value of 0,707575, which means that it does not exceed the t-table value at the 95% confidence level, which is 2,045. The HBIM component feasibility test showed a percentage of 85,68%, and the usability test showed a percentage of 83,7%. Thus, the Borobudur Temple HBIM is very feasible to be implemented in supporting asset management and architectural heritage conservation activities.

Keywords : Heritage Building Information Modelling (HBIM), Borobudur Temple, asset management, close range photogrammetry