

## Article

# Estimated Construction Order of the Major Shrines of Sambor Prei Kuk Based on an Analysis of Bricks

Ichita Shimoda <sup>1,†</sup>, Etsuo Uchida <sup>2,†</sup>  and Kojiro Tsuda <sup>2,\*</sup>

<sup>1</sup> World Heritage Studies, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tennodai 1-1-1, Tsukuba, Ibaraki 305-8571, Japan

<sup>2</sup> Department of Resources and Environmental Engineering, Faculty of Science and Engineering, Waseda University, Ohkubo 3-4-1, Shinjuku, Tokyo 169-8555, Japan

\* Correspondence: shimoda@heritage.tsukuba.ac.jp

† These authors contributed equally to this work.

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**Abstract:** Sambor Prei Kuk is a predominantly brick monument complex identified as Ishanapura, the capital of the Chenla Dynasty, which reached the height of prosperity in the first half of the 7th century. In the east area of this ancient city, the religious area was formed by three temple complexes which are composed of brick shrines and a multiple number of smaller temples with single or a few shrines scattered in the area. One of the challenging issues is to identify the dates and order in which these structures are constructed. Previous studies based on epigraphy and decorative style have estimated a simple dating of the three temple complexes. In this research, 59 major brick structures which are relatively well preserved in this area were analyzed in terms of the size and chemical composition of their component bricks. This analysis revealed that these brick structures can be classified into several groups corresponding to construction stages. The results revealed that the individual shrines in each temple complexes were built in a more complex process than previously stated, and the construction stages of the individual shrines in the vicinity were also identified as an equally complex process.

**Keywords:** construction order; architectural chronology; brick; X-ray fluorescence analyzer; Khmer; Sambor Prei Kuk; pre-Angkor; Southeast Asia

## 1. Introduction

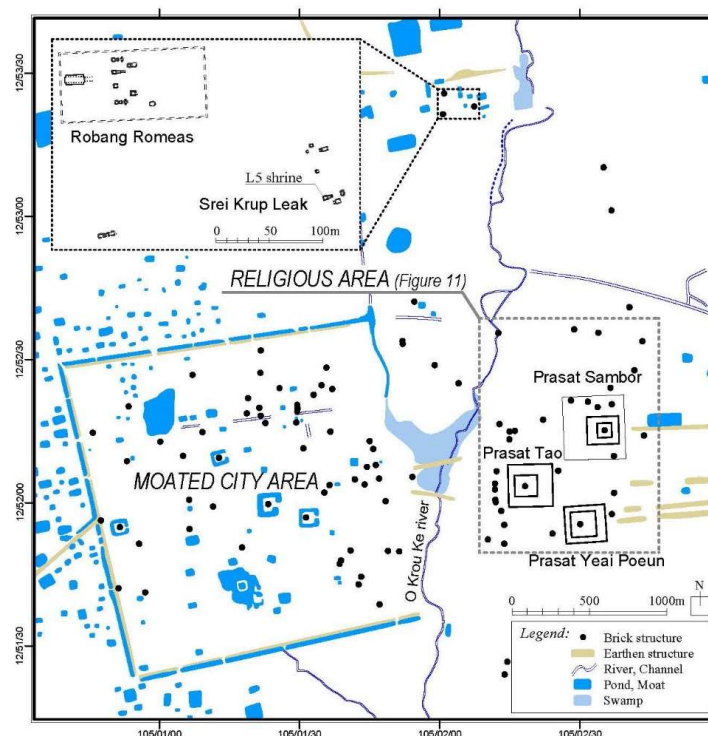
Sambor Prei Kuk is the ruin of the capital city of the Chenla Dynasty, located in Kompong Thom in modern Cambodia, and is identified as *Ishanapura* based on epigraphic studies [1] (Figure 1). An inscription in this ancient city dates back to the end of the 6th century, and the major buildings are believed to have been constructed in the first half of the 7th century [2,3]. The name of this city also appears in Chinese historical literature as “伊奢那城” (literally, Ishana castle). Among them, the *Book of Sui* (No. 82, Biography 47, Chenla articles) contains a particularly descriptive passage, and provides an early record of Ishanapura in the first half of the 7th century. The *Great Tang Records on the Western Regions*, a travel and topographical record by a Tang Buddhist monk named Xuan Zang, contains mention of “伊賞那補羅國” (Ishanapura) as one of the six South Sea states indicating that the prosperity of the Chenla Dynasty extended to foreign countries.



**Figure 1.** Location of Sambor Prei Kuk in Kompong Thom Province, Cambodia.

Although this ancient site was identified as the capital city of king Isanavarman I (616–635 AD), other kings such as Bhavavarman I (550–600 AD), Mahendravarman (600–616 AD), and Bhavavarman II (639–657 AD) also seemed to have settled at least in the vicinity. Furthermore, this site was sometimes identified as Baladityapura, which was one of the cities during the reign of Jayavarman I (657–681 AD) [4]. It is highly certain that Sambor Prei Kuk was the royal city or center of power of at least four continuous kings from Bhavavarman I to Bhavavarman II, and many of the structures in this site were constructed during this period.

The east side of Sambor Prei Kuk comprises a religious area centered on three temple complexes which are dedicated to Hinduism deities (Figure 2). The west side is a city area surrounded on three sides by a 2 km moat, with a distribution of numerous brick shrines inside and outside the moated city limits.



**Figure 2.** The core area of Sambor Prei Kuk, showing the location of brick structures, earthen structures, channel, moat, and artificial ponds. The eastern religious area is separated from the western moated city area by the natural river O Krou Ke.

Although studies on Sambor Prei Kuk have been undertaken since the first half of the 20th century, they were concentrated on the religious area, which comprised many intact well-defined shrines. In recent years, Shimoda and Shimamoto [5] conducted research in a broader area that included the city and surrounding areas that have never been surveyed in depth. Through this survey, various types of structures, not only brick buildings but also traces of numerous ponds, embankments, and waterways have been documented in the city and surrounding areas. This renewed awareness expanded the knowledge of Sambor Prei Kuk as a significant archaeological site enabling a better understanding of the formation of ancient Khmer urban cities.

In addition, they conducted research in the temple area to include a survey for revising the precise architectural records and archaeological studies. In particular, archaeological excavation surveys in the precinct area of Prasat Sambor provided the evidence to surmise the initial stage of this temple and several reconstruction processes. By unearthing several buried structures and stone artifacts through these archaeological surveys, they were able to identify the essential information needed to assemble the chronology of this temple complex.

## 2. Review of the Previous Chronological Studies

This paper sets out to reveal in detail the construction order of the brick shrines in the temple complexes, Prasat Sambor, Prasat Yeai Poeun, and Prasat Tao and several brick shrines that are located in their vicinity. The dating of temple construction has, so far, been examined based on inscriptions, the styles of deity statues, and the style of decorative lintels. From previous studies, the following simple chronology of events can be estimated: majority of the brick shrines including Prasat Sambor and Prasat Yeai Poeun were constructed in the beginning of 7th century during the reign of Isanavarman I; Prasat Tao was constructed in the earliest stage of the Angkor period; and large-scale renovation works were done in Prasat Sambor in the 10th century. However, our research on the brick material at 52 major shrines in and around these three temple complexes suggest a more complex construction order. In the following segments, we will review the available materials which supported the previous chronological presumption as premises for our research before describing the method and results of brick analysis.

### 2.1. Inscriptions

A total of seventeen inscriptions were found in the religious area (Table 1). These inscriptions were found on the site by Leclère [6], Lunet de Lajonquière [7,8], Morand [9], Parmentier [10–12], and Goloubew [13]. Finot [1,14] began the epigraphic study and Cœdès [2,3,15] advanced his study. More recently Jacques [16] and Vickery [17] have expanded the study and developed pre-Angkorian social, economic, and political evaluations.

**Table 1.** Chronological evidence for each building by previous studies on inscriptions and art style, the values of brick thickness, and Rb and Ti contents.

Location	Building	Brick Thickness	Rb (ave. value)	Ti (ave. value)	Date of Inscription	Style of Statue	Style of Lintel
<i>Prasat Sambor</i>							
on the Central Terrace	N1	77.7	67.9	2804			
	N1Ex	70.5	74.8	2075			
	N3	55.6	42.9	4766			Prei Khmeng style (shorten)
	N4	54.0	12.0	6112			SPK style (shorten)
Central Terrace	N1T	79.6	45.0	2919			
inside I. enclosure	N7	65.0	71.0	2597		Pre-Rup style (Vajimukha)	SPK style
	N8	81.3	64.1	2398			
	N9	73.8	63.0	2282		Pre-Angkor style (Durga)	
	N10	68.8	52.0	2068		Pre-Angkor style (Harihara)	
between I. and M. enclosures	N11	67.2	69.7	2418			SPK style
	N12	66.0	96.0	2909			
	N13	69.3	54.8	2539			
	N14-1	59.2	4.6	4862	7th century (K.437)		SPK style
	N14-2	62.0	17.8	5547			SPK style
East gate of M. enclosure	N25		(laterite structure)		10th century (K.436)		Angkorian style
between M. and O. enclosures	N15	73.0	53.3	2450	10th century (K.148)		SPK style
	N16		(laterite structure)		7th century (K.438)		
	N18	74.5	31.1	4147	7th cenruty (K.149)		
	N22	82.3	87.2	2627		Pre-Angkor style (Brahma)	Prei Khmeng style

Table 1. Cont.

Location	Building	Brick Thickness	Rb (ave. value)	Ti (ave. value)	Date of Inscription	Style of Statue	Style of Lintel
<b>Prasat Yeai Poeun</b>							
on the Central Terrace	<b>S1</b>	57.7	64.1	2638	no dating (K.607)		Unique style (4 lintels)
Central Terrace	<b>S1T</b>	59.1	32.4	3562	no dating (K.609, 610, 611)		
between S1 and S2	<b>S1-S2</b>				7th century (K.608)		
inside I. enclosure	<b>S2</b>	66.0	59.4	3184	7th century (K.442)		SPK style
Gate of inner enclosure	<b>S3</b>	64.1	32.5	5801			
	<b>S4</b>	56.2	26.1	4670			
	<b>S5</b>	64.3	23.7	3602	no dating (K.612)		SPK style
	<b>S6</b>	61.2	9.1	4160			
	<b>S7</b>	59.1	43.4	2420			SPK style
inside I. enclosure	<b>S8</b>	60.6	52.4	2349			SPK style
	<b>S9</b>	61.9	72.5	3079			SPK style
	<b>S10</b>	61.8	61.0	2302			SPK style
	<b>S11</b>	64.7	53.0	2348			SPK style
East gate of O. enclosure	<b>S15</b>		(laterite structure)		7th century (K.440)		
West gate of O. enclosure	<b>S16</b>		(laterite structure)		7th century (K.441)		SPK style
between I. and O. enclosures	<b>S17-1</b>	67.2	45.9	2565			
	<b>S17-2</b>	62.1	11.1	3224			
	<b>S17-3</b>	60.8	29.2	2500			
	<b>S17-6</b>		(laterite structure)		7th century (K.605)		
	<b>S18-3</b>		(laterite structure)				SPK style (2 lintels)

Table 1. Cont.

Location	Building	Brick Thickness	Rb (ave. value)	Ti (ave. value)	Date of Inscription	Style of Statue	Style of Lintel
<b>Prasat Tao</b>							
inside I. enclosure	<b>C1</b>	63.3	67.6	2518			Prei Khmeng style (4 lintels)
	<b>C16</b>	51.1	16.5	4997			
Gate of inner enclosure	<b>C10</b>	52.7	15.4	4394			
between I. and O. enclosures	<b>C17-1</b>	50.4	19.5	4943			
	<b>C17-2</b>	55.2	19.7	4697			
	<b>C18-1</b>	54.9	30.1	4378			
	<b>C18-3</b>	62.0	34.6	4566			
	<b>C18-5</b>	58.7	32.2	5684			
	<b>C18-6</b>	53.3	19.9	4687			
<b>North of Pr. Sambor</b>							
	<b>N19</b>	68.9	20.7	5039			
	<b>N20</b>	63.0	13.1	3067	7th century (K.439)		SPK style
	<b>N21</b>	61.7	55.9	2827			SPK style (on brick)
	<b>N24</b>	60.7	40.9	4696			
<b>Among three temple complexes</b>							
	<b>S12</b>	66.9	45.0	4347			
<b>West side</b>							
	<b>C2</b>	58.7	5.6	3992			
	<b>C3</b>	60.8	30.3	4221			
	<b>C4</b>	55.3	10.7	6028			
	<b>C5</b>	60.5	37.4	3914			
	<b>C6</b>	59.1	7.7	5328			
	<b>C7</b>	65.9	39.2	5345			
	<b>Y</b>	62.6	21.8	4066			
	<b>Z1</b>	59.5	19.3	4460	Angkor period (K.443)		SPK style

Five inscriptions were found at a temple complex, Prasat Sambor: K.148, K.149, K.436, K.437, and K.438. Three inscriptions (K.149, K.437, and K.438) contain the name Isanavarman I and may be contemporaneous with his reign. On the other hand, K.148 and K.436 were considered to be inscriptions from the 10th century. In particular, K.436 contains the description of the refoundation of this temple at that time. At Prasat Yeai Poeun, ten inscriptions were found: K.440, K.441, K.442, K.604, K.607, K.608, K.609, K.610, K.611, and K.612. Their contents suggest that the temple was constructed during the reign of Isanavarman I. A specific date, 549 Saka (627 AD), for the foundation of a linga appears in the inscription K.604, engraved on the doorjamb of a small shrine, numbered S17-6. On the other large temple complex, Prasat Tao, no inscription has been found to date. In addition to these inscriptions from three temple complexes, several inscriptions have been found in the surrounding shrines. On both doorjamb of a brick shrine, numbered N20, the inscription K.439 contained the name Bhavavarman II. Although a brick shrine numbered Z1 has the graffiti-like inscription K.443 from the Angkorian period, it is estimated that this inscription was added much later than the initial construction period.

As identified above, many of the seventeen inscriptions correspond to the reign of Isanavarman I (Table 1). In addition, it is important to note that even though some inscriptions indicate later periods such as the King Bhavavarman II and Angkor periods, they are not sufficient evidence to verify that construction occurred in the same period as these inscriptions.

## 2.2. Style of Deity Statues

It is thought that all shrines originally had a deity statue in the chamber; however, many of them have been lost to looting and destruction. Only four statues which could be identified with their original location still exist (Figure 3). The provenance of these four statues was identified in the shrines of Prasat Sambor (Table 1).



**Figure 3.** Deity statues which were identified as having provenance in the Sambor Prei Kuk monuments: (a) Harihara image (N10 shrine); (b) Durga image (N9 shrine, replica statue, original statue is displayed in the National Museum of Phnom Penh); (c) Brahma image (N22 shrine, replica statue, original statue is displayed in the National Museum of Phnom Penh); (d) Vajimukha or Kalkin image (N7 shrine, displayed in the Guimet Museum).

The Harihara image, which belongs to the pre-Angkorian style, was identified as the deity of the N10 shrine [18]. The original location of the Durga image is not certain, but it is believed that the N9 shrine was the provenance of this statue [5]. According to Boisselier [19], this image also belongs to the pre-Angkorian style. A Brahma image of pre-Angkorian style was found at the shrine N22 [18]. While the above three statues show the pre-Angkorian style, another statue of a Vajimukha or Kalkin image found at the N7 shrine, which is now displayed in the Guimet Museum, shows the pre-Rup style in the



Angkor period [20]. Although the N7 shrine is a single building of the octagonal plan in this temple complex, it has been identified as having been constructed in the pre-Angkorian period. Therefore, this statue is considered to have been a replacement in the later period for the deity originally enshrined. Although limited, the number of the statues in Prasat Sambor testify to the installation of the statues being done in the pre-Angkorian period and to an event which included the replacement of a statue that occurred in the 10th century.

### 2.3. Style of Decorative Lintels

Decorative lintels are commonly a key element for identifying the period of construction through their style of art. A total of fifty-nine decorative lintels belonging to this monument complex have been confirmed at this site, in museums, and storage.

A total of nine decorative lintels have been identified with their individual shrines at Prasat Sambor: N3, N4, N7, N11, N14-1, N14-2, N15, N22, and N25 (Table 1). Among these, only one remains in its original position at N22. Six were unearthed during the recent excavation survey around N3, N4, N7, N14-1, N14-2, and N25. The provenance of the lintels of N11 and N15 which are in storage have been identified by old photographs.

Many of them belong to the Sambor Prei Kuk style which is the most typical style in this monument complex (N4, N7, N11, N14-1, N14-2, and N15) (Figure 4); only two belong to the Prei Khmeng style which is a contemporary or later style than the Sambor Prei Kuk style (N3 and N22) (Figure 4). The ornament carving of the lintel at N25 is unfinished, but its shape looks more similar to the Angkorian period than the pre-Angkorian period. In fact, the inscription on this door jamb (K.436) has contents relating to the Angkorian period. The excavated lintels of two corner shrines on the central terrace (N3 and N4) were modified by the cutting off at both of the ends. Additionally, the excavated colonnettes of the N4 shrine were also modified by the cutting off at both of the ends. This evidence suggests that these lintels and colonnettes belonged to earlier larger shrines and were shortened in order to be reused in these smaller shrines in the later period.



**Figure 4.** Styles of the decorative lintels: (a) Sambor Prei Kuk style (N7 shrine); (b) Prei Khmeng style (N22 shrine); (c) Kompong Preah style (north face, C1 shrine).

A total of fourteen decorative lintels were identified at Prasat Yeai Poeun: S1 (four lintels), S2, S5, S7, S8, S9, S10, S11, S16, and S18-3 (two lintels). Except for four lintels at the S1 shrine, all of them belong to the Sambor Prei Kuk style. Lintels of the S1 shrine are quite different from the others, in that



the lintels above the front and back doors are engraved in narrative motives. It may be interpreted that this unique design was to represent the significance of the central shrine. The engravings on two lintels from the S18-3 shrine are incomplete but are of the Sambor Prei Kuk style. Thus, as the lintels in Prasat Yeai Poeun are unified in the same style, it is assumed that the entire design and construction work was carried out as a single project.

At the third temple complex of Prasat Tao, all four lintels belonging to the central shrine C1 survived. This temple has very limited clues to estimate the construction period, because all shrines except for the central one are severely collapsed. No inscriptions or sculptures have been discovered, and no archaeological excavation survey has been conducted to date. Therefore, there are only weak assumptions for their dating, but it is generally thought that this temple was built in the 9th century during the reign of Jayavarman II, who founded the Angkor Empire. This is because these decorative lintels and colonnettes in the central shrine are of the Kompong Preah style which appeared in the later stage of the pre-Angkor period (Figure 4). Additionally, lion images protecting the door openings resemble those in Phnom Kulen which has been evaluated as the sculptural style in the 9th century [21,22].

Among the surrounding individual shrines, one lintel has been identified in its original location. This lintel belongs to the N20 shrine and shows the style of Sambor Prei Kuk. Finally, brick shrine N21 has lost the original stone decorative lintel; however, the lintel decoration was engraved on the brick masonry above the false door. The style of this engraving is also of the Sambor Prei Kuk style.

#### 2.4. Architectural Modifications

A series of archaeological excavation surveys have been conducted at Prasat Sambor in recent years. Through these works, several traces of architectural modification were confirmed at each structure; the N1 central shrine, central terrace, N3 and N4 corner shrines on the central terrace, N14-2 shrine, N6-1 east gate of the inner enclosure, and N25 east gate of the middle enclosure [5,23].

An evaluation of the brick masonry of the N1 shrine after the clearance of the accumulated soil and fallen bricks around the structure revealed that the base, pilaster, and the pediment above the door openings were later additions and replacements (Figure 5). As the decorative engraving on the base is the same style as the other elements, this modification work seems to have been carried out immediately after the initial construction work. Evidence of the modification was confirmed on the top surface of the central terrace which emplaces this central shrine. After removing the accumulated soil on this terrace, four rows of pillar holes have been confirmed on the top surface of the terrace on the east side of the central shrine, suggesting that a wooden antechamber had been added to the front of this shrine. This kind of the modification is presumed to be of the late-Angkorian period because many temples in the Angkor area have the same traces of an additional wooden antechamber in front of shrines and gates in the late-Angkorian period. Traces of an additional wooden structure in front of shrines has been confirmed at several other shrines in Prasat Sambor and Prasat Yeai Poeun.

Two more shrines, N3 and N4, were also confirmed from the corners of the central terrace by the clearance of the accumulated soil. The brick masonry of these structures is significantly less precise compared to the other buildings. As mentioned above, unearthed lintels and colonnettes from these structures were cut off at both ends and reused. It is fairly certain that these two shrines were built later than the other shrines in this temple complex.

Several reconstructed stages of structures were confirmed at both the east gates of the inner and middle enclosures by archaeological excavation surveys. Four or five different stages of structures were estimated at the gate of the inner enclosure (N6-1), and three stages of structures were estimated at the gate of the middle enclosure (N25). Because all reconstructed structures at the east gate of the inner enclosure wall (N6-1) were significantly low-quality brick work, it is likely that they were added after this temple lost its significant status. On the other hand, the latest reconstruction work of the middle enclosure might have been carried out in the 10th century because of the inscription of the 10th

century (K.436) and the decorative lintel in the style of the Angkorian period belonging to the third stage of this structure.



**Figure 5.** Eastern view of the N1 shrine at Prasat Sambor (after restoration work). Additional brick work is observed at the base and pilaster. The pediment ornament on the door frame is also likely to be added masonry at the western and northern elevation. The rows of pillar holes were confirmed on the pavement of the terrace only on the eastern side of the central shrine.

Thus, with the abovementioned evidence, modifications and additions are confirmed for the several structures in Prasat Sambor. Although it is difficult to identify with certainty the dates of these events, it is obvious that some of these events occurred in later than pre-Angkorian period. The estimated periods for these modifications are based on the quality of the brick masonry and the date of the inscriptions and styles of the architectural elements, and range widely from immediately after the initial construction work to the late- or post-Angkorian period when Prasat Sambor ended its important role as the regional religious center.

### 3. Survey Method

The aim of this paper was to deduce the construction order of the buildings in each temple complex based on the size and chemical composition of bricks, which is the main construction material in this group of monuments. We carried out the analysis at 52 major brick buildings in the east temple area. Although we tried to survey all brick structures, the buildings where a sufficient number of samples could not be obtained were excluded from the following analysis. The N1 shrine, which is suspected of being modified partially in later years, was analyzed separately (N1 and N1Ex).

#### 3.1. Measurement of Brick Size

At the Angkor monuments, the size of the bricks tended to have gradually increased with the progression of time. The Angkorian thickness of bricks is around 40 mm in Preah Ko at the end of the 9th century, but 80 mm in Pre Rup in the late 10th century [24]. However, at Sambor Prei Kuk, the bricks are considerably larger than those in the early Angkorian period. The bricks at Sambor Prei Kuk generally have a 4:2:1 ratio with regard to length, width, and thickness, but their actual size is not accurately uniformly sized within the same building.

The thickness of the bricks was measured as there is a clear difference among the buildings; however, the value of the bricks' thickness in each building is highly homogeneous. Basically, for brick buildings, ten continuous tiers of bricks were measured in three locations to obtain the average thickness of individual bricks. For collapsed shrines, 10 to 30 scattered bricks were measured to obtain an average value.

### 3.2. Chemical Composition Analysis

The chemical composition was analyzed for five bricks from each building. Using the Innov-X Systems Delta Premium Portable X-ray fluorescence analyzer, the bricks were measured in soil mode for 60 s. Prior to the measurement, calibration was conducted using ten standard Japanese rock samples. In the measurement, the surface of the bricks was cleaned with a brush to obtain accurate data. Because of the variation in the measured value, the mean value from at least five bricks were used (Supplementary Materials Data S1).

The difference in the chemical composition of bricks may be attributable to the difference in provenance of the raw materials, which may indicate different a brickmaker. If this is so, a deeper consideration raises the possibility that the buildings had been built during the same period but using different bricks from several construction groups, or that they had been built in different periods. Thus, the reason for any difference in chemical composition must be judged carefully. Nevertheless, in the recent analysis of bricks, the difference in chemical composition was interpreted as providing meaningful data on the difference in construction periods.

In other ancient Khmer monuments, such as Koh Ker, the analysis of the chemical composition of brick material provided valuable evidence for identifying the construction sequence [25], and the analysis of the chemical composition and magnetic susceptibility of laterite materials have aided in deducing the construction sequence of each building [26]. In addition, the sandstone study of Khmer monuments in Thailand successfully identified the provenance of the sandstone materials by chemical composition [27].

## 4. Results

With regard to the buildings in the east area of Sambor Prei Kuk, the bricks of the N22 shrine were the thickest (82.3 mm), and those of the C17-1 shrine were the thinnest (50.4 mm). On the whole, the majority of the bricks were around 60 mm thick. At Prasat Sambor, most of the bricks from the shrines were 65 to 80 mm thick. The bricks at Prasat Yeai Poeun were 55 to 65 mm thick, and those at Prasat Tao were around 50 to 60 mm thick (Table 1).

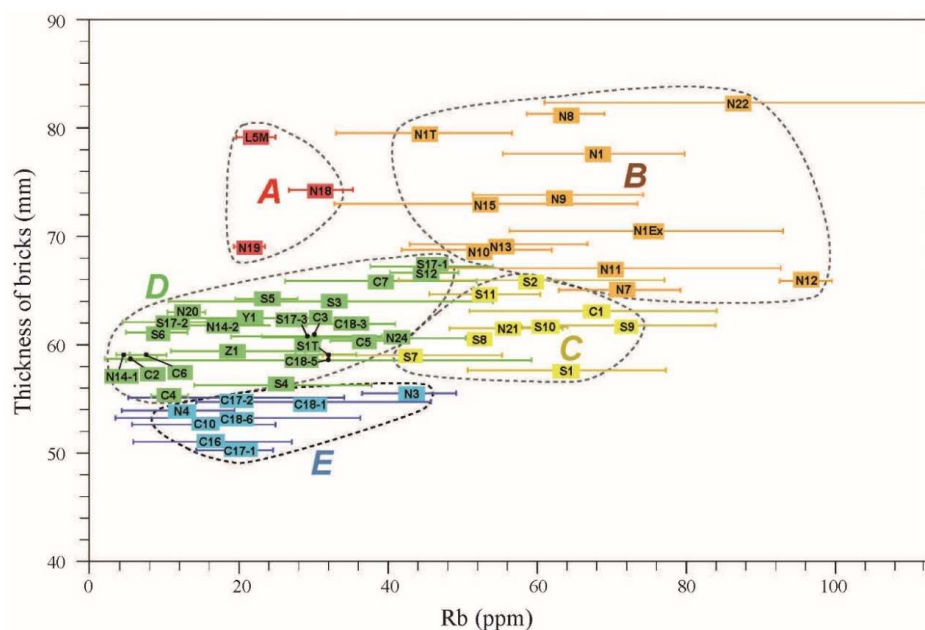
The chemical composition including Ti, Mn, Fe, Zn, Rb, Sr, and Zr were analyzed with good precision by a portable XRF in soil mode for all the bricks and are summarized in Supplementary Materials Data S1. Among these elements, Rb and Ti showed reasonable relationships with the brick thickness, which are concordant with the features of architectural modifications and the shrine layout in each temple complex. In addition, this relationship was consistent with the rough construction order from Prasat Sambor and Prasat Yeai Poeun temple complexes to Prasat Tao temple complex, which has been estimated from the previous studies on the decorative style of each shrine. Rubidium (Rb) was the highest at the N12 shrine (96 ppm) and the lowest at the N14-1 shrine (4.6 ppm). Titanium (Ti) was the highest at the N4 shrine (6112 ppm) and the lowest at the N10 shrine (2068 ppm).

## 5. Considerations

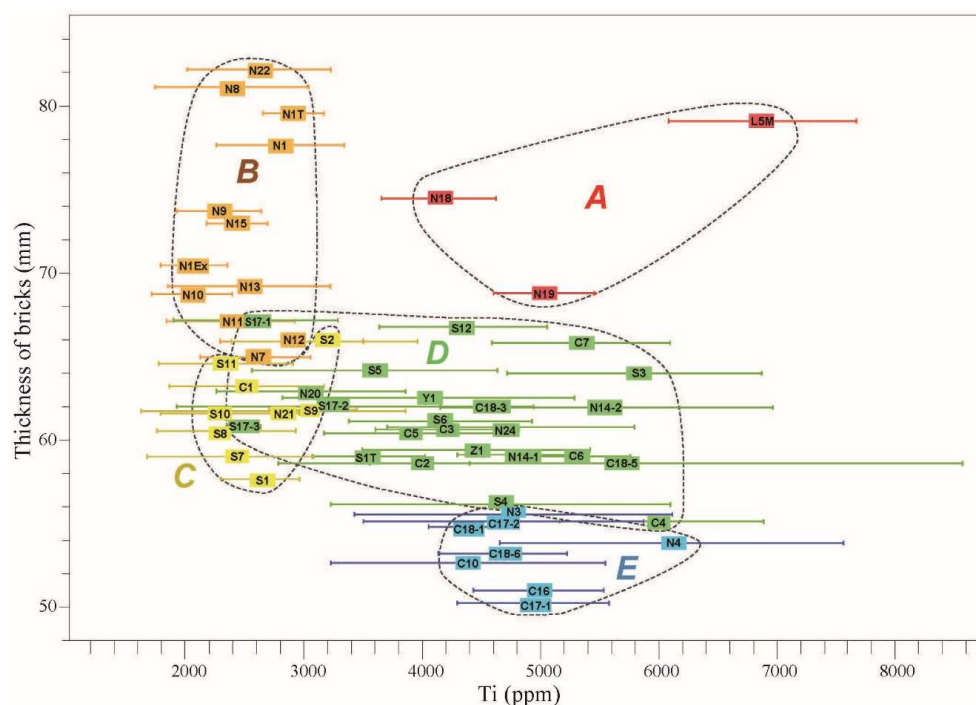
### 5.1. Classification and Construction Order of Brick Buildings in Three Temple Complexes

Figure 6 shows the relationship between brick thickness and Rb content and Figure 7 shows the relationship between brick thickness and Ti content. The main brick structures in Prasat Sambor (N1, N1Ex, N1T, N7, N8, N9, N10, N11, N12, N13, N15, and N22) are distributed in a narrow area in the both figures. The shrines in this area are classified into Group B. Most of the shrines in this temple

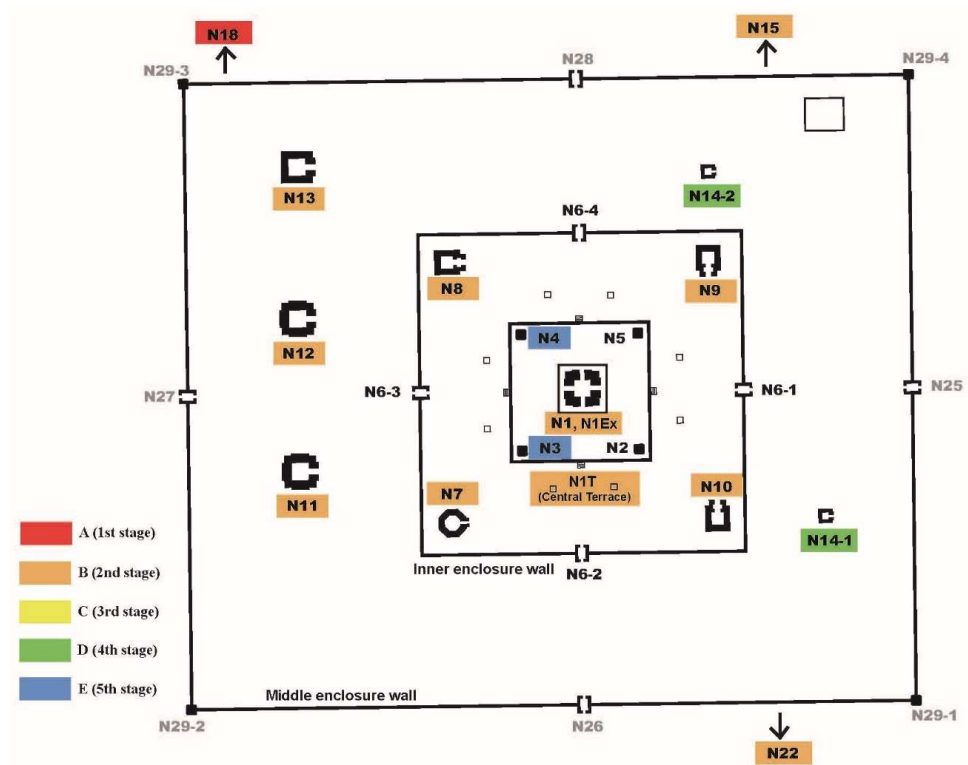
belong to this group (Figure 8). The gray numbered shrines in Figures 8–10 are made of materials other than brick.



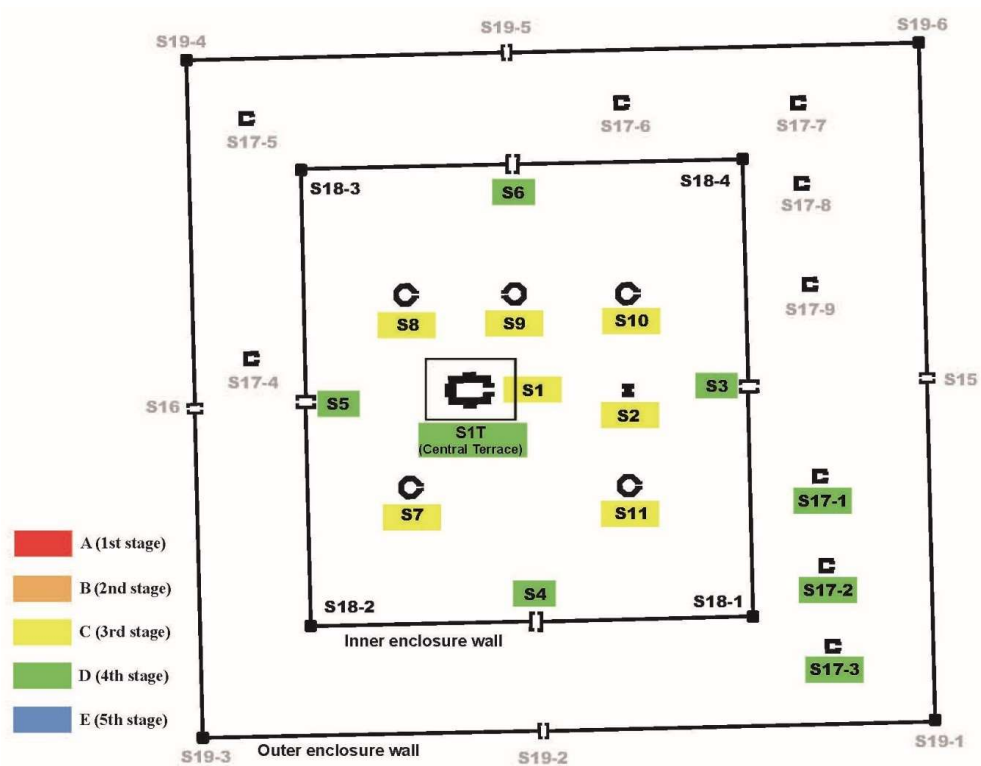
**Figure 6.** Relationship between brick thickness and rubidium (Rb) content (average value and the range of standard deviation). A total of 59 major brick structures in the religious area of the Sambor Prei Kuk monuments were analyzed and divided to 5 groups.



**Figure 7.** Relationship between brick thickness and titanium (Ti) content (average value and the range of standard deviation). A total of 59 major brick structures in the religious area of the Sambor Prei Kuk monuments were analyzed and divided to 5 groups.

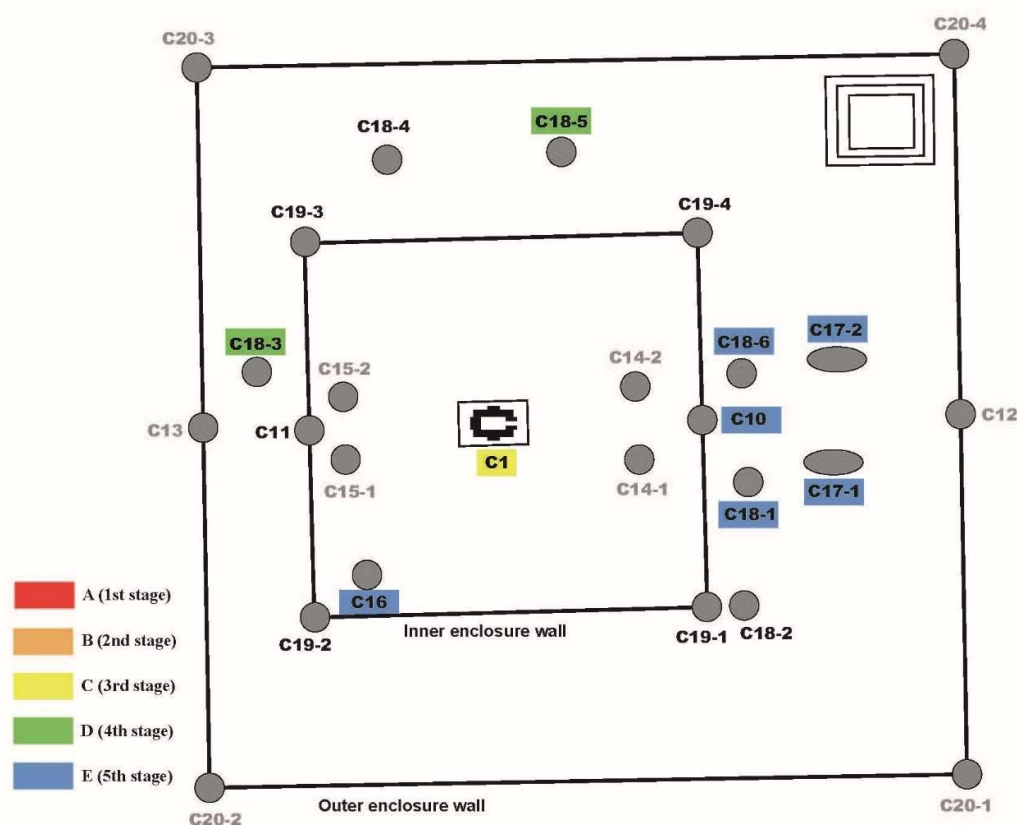


**Figure 8.** Estimated construction stages of the brick shrines at Prasat Sambor on the basis of the results of brick thickness and Rb and Ti content measurements.



**Figure 9.** Estimated construction stages of the brick shrines at Prasat Yeai Pouen on the basis of the results of brick thickness and Rb and Ti content measurements.





**Figure 10.** Estimated construction stages of the brick shrines at Prasat Tao on the basis of the results of brick thickness and Rb and Ti content measurements.

As described above, elements of the initial brick building (N1) and the additional elements (N1Ex) were measured separately because of the partial modification of this shrine. As the bricks of both elements are classified into the same Group B, it is reasonable to consider that the later additions were done not long after the initial construction. This assumption is also consistent with the analysis from the stylistic point of view, that is, the additional and original elements of the decorative style are the same or resemble each other very closely.

The N15 and N22 shrines, which are situated in exactly the same symmetrical position to each other across the main axis line of the Prasat Sambor complex, are considered to have been built in the same period following this classification. As mention above, N22 has a decorative lintel of the Prei Khmeng style that is a relatively later style than that of the Sambor Prei Kuk style. However, the result of the brick analysis was not contradictory, because these styles are thought to have a period of overlap. Regarding the N15 shrine, which has an inscription of the 10th century, there is little doubt that it was built during the pre-Angkorian period because of its architectural and decorative lintel styles. Therefore, it is reasonable to consider that N15 and N22 were built at nearly the same time as the major components of Prasat Sambor.

Shrines located in the inner enclosure wall of Prasat Yeai Poeun (S1, S2, S7, S8, S9, S10, and S11) are also distributed in a narrow area, as shown in Figures 6, 7 and 9. The shrines in this area are classified into Group C. The central terrace of this temple (S1T) is out of this group.

Each gate of the inner enclosure wall (S3, S4, S5, and S6) and the shrines between the inner and outer enclosures of Prasat Yeai Poeun (S17-1, S17-2, and S17-3) are distributed in the same area in Figures 6 and 9. The structures in this area are classified into Group D. In Figure 7, the distribution of these structures is overlapping with Group C. Because it is reasonable to consider that the construction

work progressed from inside to outside in this temple complex, it is presumed that the construction work of Group D was started after the completion of the shrines of Group C.

A total of nine small shrines were built between the inner and outer enclosures, but the S17-1 to S17-3 shrines located on the southeast side were made of brick and the remainder made of laterite. It appears that the construction of a series of brick shrines on each side was planned as the original design, but after the completion of three southeastern brick shrines, they changed to laterite construction, and eventually, the construction work was abandoned before completing all shrines.

The central terrace of this temple (S1T) is classified as Group D. The S1 shrine, which is a building of Group C, stands on this terrace, but the decoration at the base of this shrine suggests the possibility that the lower part of this shrine had become hidden when the terrace was added later. In order to confirm this modification process, it is necessary to conduct a partial dismantling survey of this terrace, but this process is reasonably presumed by the result of this brick analysis.

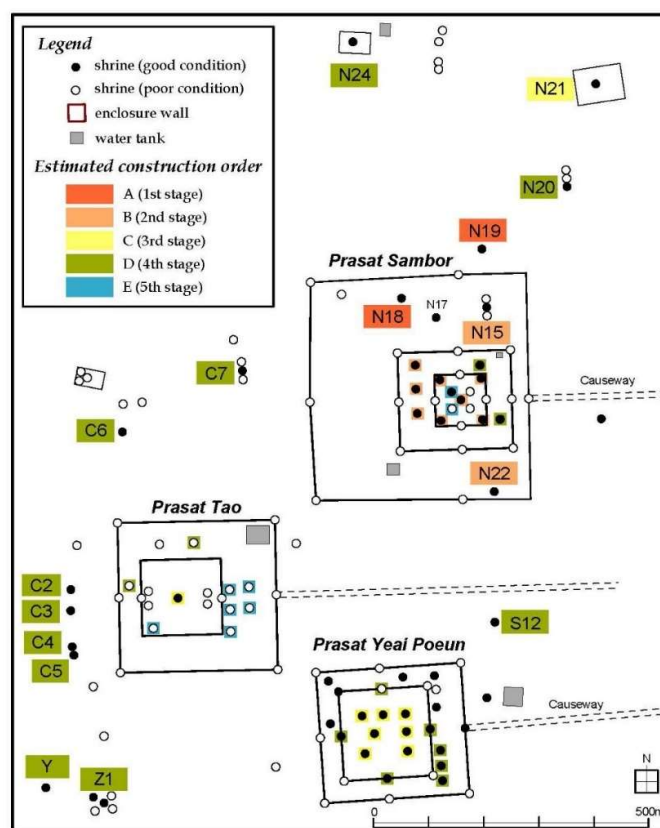
Buildings in Prasat Tao (C10, C16, C17-1, C17-2, C18-1, and C18-6), except for the central shrine C1, are distributed in a narrow area, as shown in Figures 6, 7 and 10. These buildings are classified as Group E. As other temples, the N3 and N4 shrines in Prasat Sambor are included in this group. As previously mentioned, these two shrines are considered to have been constructed in the latest stage in this group on the basis of reused decorative materials. Thus, the structures of Group E are thought to be the latest stage of the entire construction work. It is noted that the central shrine of Prasat Tao (C1) is classified into Group C, and two shrines, C18-3 and C18-5, are classified into Group D. Although the construction period of the central shrine was generally estimated to be the latest stage of the pre-Angkorian or the earliest of the Angkor period based on the style of the lintels and lion statues, the results of this analysis does not support this presumption. It is considered that the construction of the Prasat Tao was started at the same period as Prasat Yeai Poeun, but it took a longer time to commence the construction works of shrines with the exception of the central shrine.

Through the analysis and observations, it was confirmed that the shrines of the three temple complexes were classified into four groups (Groups B to E), and Groups C, D, and E were arranged in chronological order. It is difficult to judge the chronological order of Group B and C, because there are no temple complexes which contain both shrines of Groups B and C. However, it can be inferred that Group B is from an earlier stage than Group C, because some shrines of Group C have the later style lintel, in particular the C1 shrine, and the bricks tend to reduce in size over time.

Additionally, the classification and construction order of the two shrines N18 and N19, which are not included in the above four groups, are considered as follows. The N18 shrine is located between the middle and outer enclosure walls of Prasat Sambor, and the N19 shrine is located at the north side of this temple (Figure 11). This location is in close proximity to the N17 shrine, which is made of sandstone plates. This is an exceptional style that has also been found in a few similar styles of buildings along the Mekong River and is generally considered an older architectural style in the Pre-Angkorian period. The N19 shrine also shows a unique architectural style, that is, a decorative molding around the wall of the first tier to give the appearance of a false upper tier.

To clarify the construction period of these shrines, the L5 shrine, which belong to the Srei Krup Leak complex, located in the northern part of Sambor Prei Kuk, is referred to here (Figure 2). The majority of the structures in this complex and the neighboring complex, Robang Romeas, have been constructed in the early Angkor period, likely between the 10th and 11th centuries, judging from epigraphic material and architectural styles [5]. However, the main chamber of the L5 shrine (L5M) shows an older decorative style. In addition, this shrine bears the oldest inscription in Sambor Prei Kuk, with a date of 598 AD during the reign of Bhavavarman I (550–600 AD). The Rb and Ti contents and brick size of the N18 and N19 shrines are similar to the brick of this structure (Figures 6 and 7). This evidence suggests that these three shrines are classified into the same group, Group A, and N18 and N19 were built in the earliest stage of construction, and at the same time, as the main chamber of the L5 shrine.





**Figure 11.** Estimated construction stages of the brick shrines in the vicinity of the three temple complexes on the basis of the results of brick thickness and Rb and Ti content.

## 5.2. Classification and Construction Order of the Surrounding Shrines

As mentioned above, the major buildings of the three temple complexes can be classified into five groups: the earliest classified as Group A followed sequentially by Groups B, C, D, and E. Other buildings which are located independently around the complex of temples were analyzed to establish a further delineation of grouping and construction order (Figure 11). In Figure 11, the black circles indicate the buildings of relatively good condition and white circles indicate the buildings demolished or in a high state of disrepair.

Four brick shrines are still in sound condition at the north side of Prasat Sambor: N19, N20, N21, and N24. The classification and construction order of the N19 shrine was discussed above and it is presumed that this shrine might be one of the earliest works in this group of temples. The N20 shrine, located on the north side of Prasat Sambor, is classified as Group D. This shrine is characterized by the edicule decoration, called flying palace, on its exterior walls that is simpler in composition compared to the same decorative element on other buildings. This shrine has an inscription from the reign of Bhavavarman II (639–657AD), and it could be interpreted that the buildings from this group were constructed during his reign. As the N24 shrine also belongs to Group D, it is thought to have been built in a similar period to the N20 shrine. The shrine N21 is classified as Group C, so it is considered to have been built earlier than the N20 and N24 shrines.

A series of shrines on the west side (C2, C3, C4, C5, C6, C7, Y, Z1, and N24) are classified as Group D. In addition, the S12 shrine that stands alone among three temple complexes is also classified as Group D. Thus, it is thought that many shrines located around these temple complexes were constructed in the stage of Group D, and these construction works were initiated prior to the completion of the temple complex of Prasat Tao.

## 6. Conclusions

Sampled brick buildings at the religious area of Sambor Prei Kuk were classified into five groups according to their brick thickness and Rb and Ti content. Bricks that were as thick as 70 to 80 mm in the older buildings diminished in size to around 50 mm over time. These five groups are concordant with the evidence on the limited number of dated buildings presented in past epigraphy and studies of decorative style, and therefore, provide an effective reference for a more detailed analysis of the construction order of most of the brick shrines. Based on the analysis of bricks, a construction order can be extrapolated.

The N18 and N19 shrines, which are classified as Group A, are considered to be the oldest shrines built in the first construction stage. This is the same group as the main chamber of the L5 shrine at Srei Krup Leak, a temple bearing an inscription date of 598 AD. Their close proximity to the N17 shrine, which displays an older sandstone architectural style, also supports this theory.

The main shrines of the Prasat Sambor complex were built next. They are classified as Group B representing the second construction stage. As the bricks of the partial additions to the N1 central shrine are classified into the same Group B, it is thought to have been built during the same period. The N15 and N22 shrines, which stand symmetrically north and south of Prasat Sambor, were also built during approximately the same period.

Thereafter, in the third construction stage, the central shrine (S1) and five sub-shrines (S2, S7, S8, S9, S10, and S11) within the inner enclosure of the Prasat Yeai Poeun complex were built. They are brick shrines that are classified as Group C. The construction of Prasat Tao also started from the central shrine C1 at this period. The independent shrine N21, which is located at a slight distance to its north, is thought to have been built during this period as well.

In the following fourth construction stage, a terrace was added to the S1 central shrine at the Prasat Yeai Poeun complex that covers the building base as well as an inner enclosure wall and small shrines built between the inner and outer enclosures. The buildings from this period are classified as Group D. Construction work in the Prasat Tao complex also continued in this stage (C18-3 and C18-5). Many shrines on the west side of the three temple complexes (C2, C3, C4, C5, C6, C7, Y, and Z1), and the isolated N20 and S12 shrines were also built during this period. Furthermore, it is highly likely that the N14-1 and N14-2 shrines at Prasat Sambor were also built between inner and middle enclosure walls during this period.

The fifth stage saw the construction of many shrines at the Prasat Tao complex, as well as the N3 and N4 shrines that stand on the central terrace at Prasat Sambor. As a whole, the construction technique tended to become poor and less precise at this stage.

Previous studies have simply conjectured that the temples were built in the order from Prasat Sambor and Prasat Yeai Poeun complex to Prasat Tao complex. However, the analysis of the bricks of each building revealed that the shrines in each temple complexes were built in a more complex timeline with additions and modifications, as well as some structures being constructed in parallel. The construction stages of several shrines that stand alone in the vicinity of the three temple complexes were also identified by this study.

It is difficult to estimate the precise dating of each construction stage using the method presented in this study; however, in consideration of dating based on inscriptions, the first stage is estimated to correspond to the end of the 6th century, and the second to third stages to the reign of Isanavarman I (615–639 AD) in the first half of the 7th century. This implies that a large number of shrines were built in stages over a relatively short period of time. The fourth stage probably corresponded to the reign of Bhavavarman II (639–657 AD) because of the dating of the inscription at the N20 shrine. Therefore, it was also deduced that the construction of Prasat Yeai Poeun could have been continuous over the reign of two kings. Many of the shrines at the Prasat Tao complex were built during the fifth stage. Although no evidence to identify this date has been found so far, it is conjectured that this large project was completed by the strong ruler who inherited the original political and religious plan.

This study provided a more detailed physical analysis of the construction order of the brick structures in the religious area of Sambor Prei Kuk than previously undertaken. The relative dating method based on brick size and chemical compositions is expected to be applied to the many other brick buildings within Sambor Prei Kuk. Because most of these structures are in a poor state of preservation and few chronological clues such as inscriptions and sculptures have been excavated, the results may be circumstantial. This method has the potential to reveal the chronology of the brick buildings in this complex group of monuments and may provide additional information to clarify the transition from the formation to decline of this ancient city.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2571-9408/2/3/118/s1>, Results of the chemical analysis of bricks by the portable X-ray fluorescence analyzer (ppm).

**Author Contributions:** Conceptualization, I.S. and E.U.; methodology, I.S. and E.U.; software, I.S., E.U. and K.T.; validation, I.S. and E.U.; formal analysis, I.S., E.U. and K.T.; investigation, I.S., E.U. and K.T.; resources, I.S. and E.U.; data curation, I.S. and E.U.; writing—original draft preparation, I.S. and E.U.; writing—review and editing, I.S. and E.U.; visualization, I.S. and E.U.; supervision, I.S. and E.U.; project administration, I.S. and E.U.; funding acquisition, I.S. and E.U.

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