FROM THE EARTH TO THE HEAVENS: ECONOMIC AND ARCHITECTURAL EXAMINATION OF ADOBE BRICKS AND BRICK MAKING AT THE THIRD MISSION SANTA CLARA

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The construction of the Third Mission Santa Clara de Asís was a truly monumental task, but quantitatively how much material and effort were required, and was the building of the Third Mission an economically sound decision? Crossing the disciplines of history, archaeology, economics, accounting, and mathematics, this paper begins the process of modeling the labor efforts, costs, and financial viability of the Third Mission by first examining the adobe bricks used to build it.

INTRODUCTION

To the reader: this is not an economics paper, nor is this an archaeology paper, *per se*. It is a culmination of various principles, approaches, and years of research to fundamentally determine value. Specifically, all other things being equal, was there an economic justification for the missionaries to build the Third Mission Santa Clara?

One needs only to gaze at the sheer quantity of archaeological remains unearthed at Santa Clara University or see the outline of the Mission's walls in the ground to recognize that the construction of the Third Santa Clara Mission was no easy feat – but what does that mean quantitatively? Using the archaeological record, historical records, economics, accounting, and mathematical modeling, it is possible to quantify the time, effort, and material required to construct the church. Then, if the total costs of construction and the costs of supporting the congregation outweigh the aggregate value of the agricultural products produced, it can be concluded that there was no financial justification for the construction of the Mission. If, however, the value of the goods produced outweighs the costs of building the church and supporting the congregation, there may be quantitative evidence that – again financially speaking – the building of the Third Mission was a viable proposition.

A BRIEF HISTORY OF MISSION SANTA CLARA

Mission Santa Clara de Asís is located in the heart of the Silicon Valley, approximately 50 miles south of downtown San Francisco and approximately 3 miles northwest of downtown San Jose. Mission Santa Clara is a registered historic landmark with the state site trinomial CA-SCL-30/H. From the Mission's founding in 1777 through today, six churches were built, all within the same general vicinity.

The First Mission Santa Clara, built of wood, was founded in 1777 and abandoned in 1779 due to flooding. A second temporary Mission was built of wood and abandoned in 1784 when the Third Mission was dedicated. The Third Mission Santa Clara – the subject of this paper – was the first one built of adobe and was inhabited for 34 years until it was heavily damaged and abandoned in 1818 due to an earthquake (Skowronek and Wizorek 1997:55). The fourth Mission Santa Clara – a temporary adobe structure - was dedicated in 1818 and abandoned in 1825 with the construction of the Fifth Mission (Skowronek and Wizorek 1997:70). The Fifth Mission Santa Clara, the last built of adobe and with Native American labor, was constructed on the location of the current Mission Church and lasted through secularization and the founding of Santa Clara University. Fire destroyed the church in 1925. The final and Sixth Mission Santa Clara was constructed after the fire in 1925 and still stands today, built of masonry and with modern construction techniques.

There are several reasons for focusing this research effort on the Third Mission Santa Clara. Of all the missions built with Native labor, the Third Mission was the most prosperous in terms of population and agricultural assets. Secondly, most of the *Informes* (statements written by the padres providing detailed accounts to the Spanish authorities on the "State of the Mission") are available for the Third Mission period. Furthermore, detailed excavations have been conducted on the Third Mission church and quadrangle, including a comprehensive study conducted in 1995 as part of the rerouting of the El Camino Real (Hylkema 1995). These studies provide a rich archaeological record – including detailed dimensions and actual data regarding the Mission's construction - to use in the mathematical models.

As the title suggests, this paper begins the analytical process of determining value and financial viability by first quantifying the effort and cost to manufacture the adobe bricks that comprised the church walls. The sheer size of the

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Mission meant a significant amount of adobe material had to be used, and therefore likely accounted for a significant if not the most significant share of effort and cost to build the church.

The Architecture of the Third Santa Clara Mission

To construct a mathematical model estimating the number of bricks that had to be made, the first step is to estimate the volume of the Mission church's walls. According to Hylkema (1995:64), the long side walls of the church are described as being 41.1 meters (135 feet) long and 1.5 meters (five feet) thick. The shorter front and rear walls of the church are described as 10.3 meters (33.8 feet) long and 1.5 meters (five feet) thick. According to Fray Thomás de la Peña, the walls of the church were eight *varas*, or approximately 6.7 meters, high (Spearman 1963:34). Unlike many other Missions, the Sacristy was physically attached to the Mission proper, divided by a small 1-meter- (3-foot-) wide wall.

Based on the dimensions of the church, there would have been at least two triangular support areas to hold up the roof, one for the front and one for the rear face of the building. The size and volume of these supports were calculated and included in the model to produce a more accurate representation of the total number of bricks necessary to build the Mission.

Several architectural elements, however, are not accounted for in the analysis. The model does not account for any windows, doors, or what had been described by Fray Tomás de la Peña as "buttresses" (Spearman 1963:34). The reason is quite simple: there are no historical records concerning the dimensions of these architectural elements. In addition, unless the doors, windows, and buttresses accounted for more than one-tenth of the total volume of the church's walls, which is unlikely, the difference in the number of bricks is likely insignificant.

Adobe Brick Analysis

More than 70 adobe bricks from the Fifth Mission Quadrangle were excavated in the early 1980s, and were analyzed for this report. These are the only surviving adobe bricks from Mission Santa Clara that could be handled, measured, and weighed for statistical purposes. Although these bricks were likely manufactured decades after the Third Mission was abandoned, the probability that the local brick-making technology changed significantly seems low, as the Fifth Mission was also built with Native laborers and construction was completed before secularization (Skowronek with Thompson 2006:364).

Working in conjunction with the Santa Clara University Archaeological Lab, an analysis of 77 adobe bricks determined that the average Mission Santa Clara brick was 47.1 cm in length (X), 23.3 cm in width (Y), and 10.1 cm in height (Z), resulting in an average dirt volume of approximately 11,100 cm^3, or 0.0111 m^3 (Figure 1). The standard deviation of all 77 bricks was a mere 1,264 cm^3, or 0.001264 m^3, equal to an 11.3 percent standard error. Thirty-five of the 77 bricks were weighed, with the average brick weighing 42 lbs. The variation in weight was similar to the variation in volume. The similarity among the bricks demonstrates the effectiveness of the Mission's manufacturing techniques to mass-produce handmade bricks with a relatively high degree of precision.

Based on these calculations and measurements and the dimensions of the Mission, approximately 100,000 bricks would have been required to build the walls of the church. Presuming half an inch of mortar was used on each side of a brick to secure it in place and hold the walls together, then a slightly smaller estimate of approximately 80,000 bricks would have been used to build the church, with the remaining displacement accounted for in mortar. Based on the standard error in brick volume, the number of bricks required to build the church ranged from a low of 71,000 to a high of 92,000, based on the upper confidence limit. Assuming that each brick weighed 19 kg (42 lbs), the bricks and mortar used to construct the walls of the church weighed more than 2,000 tons.

Furthermore, the calculated minimum, average, and maximum numbers of bricks manufactured to build the Third Mission are almost certainly underestimated, for two key reasons. One, only the bricks used to construct the church and the adjoined sacristy are addressed in the model. The bricks required to build the Mission quadrangle, any support buildings, etc. associated with the Third Mission, are not included in this estimate. Secondly, breakage is not included. If we assume that only 10 percent of all the bricks were discarded due to manufacturing defect, or if only 10 percent of the bricks produced broke at some point in the construction process, then in reality an average of 88,000 bricks was actually produced. If one quarter of all the bricks made were discarded or broken, then 100,000 bricks were actually produced.

To put these figures into perspective, if each brick was laid end-to-end, there would be enough to stretch approximately 30 miles – or roughly the distance from San Jose International Airport to San Francisco International Airport. At 19 kg (42 pounds) apiece, the total weight of all the bricks is roughly equivalent to the weight of five Boeing 747-400 aircraft (Boeing Corporation 2007).

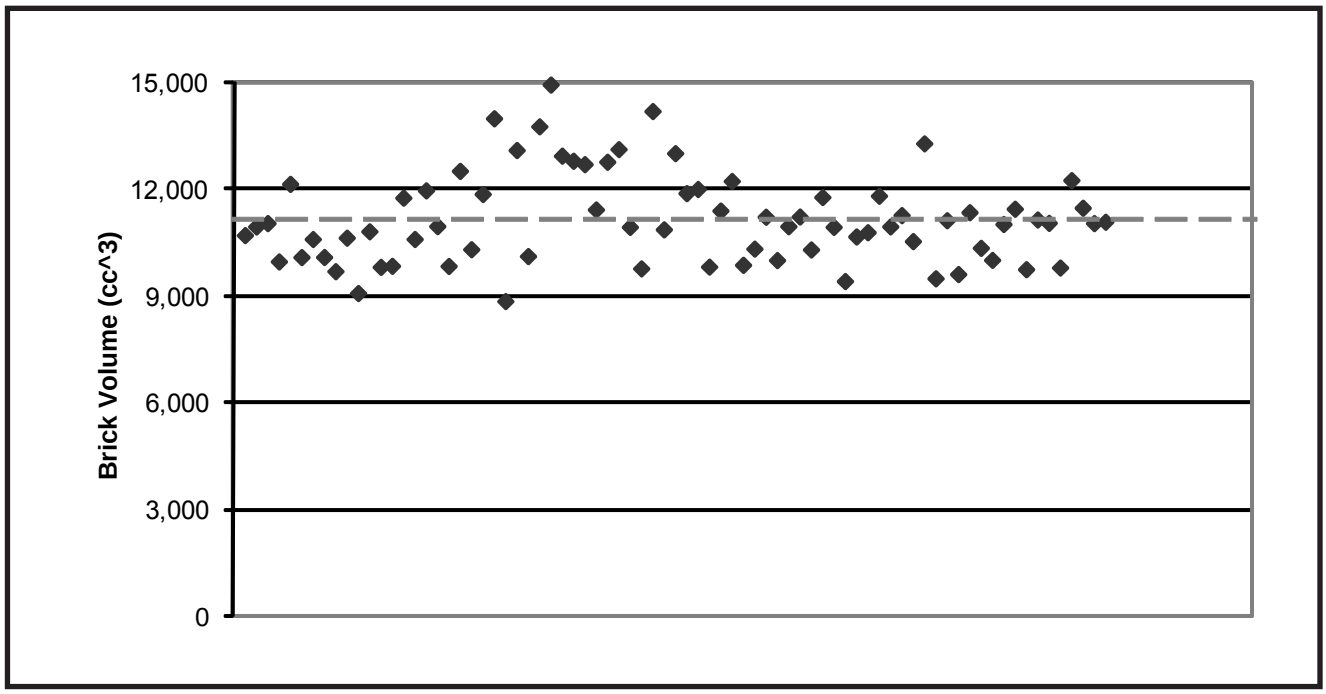

Figure 1. Seventy-seven adobe bricks from the Fifth Mission Santa Clara quadrangle were measured and the average volume calculated. The average brick based on the sample had a volume of 11,100 cm^3 (trend line) with a standard deviation of 1,264 cm^3.

An additional line of inquiry was taken when analyzing the bricks. In conjunction with the Santa Clara University Archaeology Research Lab, a 10-pound section of a broken adobe brick (or approximately one-quarter the size of a mathematically "average" brick) was submerged in water to dissolve it into its separate ingredients, and the remains were sorted by type. Five categories of material were recovered from the brick sample, including: trace elements of charcoal (0.12 g); two small, unidentifiable bone fragments (0.17 g), fired clay, such as roof tile fragments (25.6 g); inorganic matter, such as gravel, rocks, clay and soil; and organic material, such as seed casings and straw (55.8 grams). Not surprisingly, inorganic matter accounted for the vast majority of material recovered (4,450 g). While further micro- and macro-botanical analyses on the organic material are being discussed, the organic remains are likely either native Bay Area grasses that no longer exist in the Santa Clara University area, or a domesticated variety of wheat imported by the missionaries (Linda Hylkema, personal communication 2002).

While not statistically significant, extrapolating from these findings and the number of bricks required to build the church, it is possible that more than one percent - or 24.5 tons - of the total material in the walls of the Third Mission was organic, comprising seed and straw remains. Presuming the majority of the organic material was a variety of wheat, using the conversion rate of 1.575 US dry bushels per fanega (Pauley 2004) and based on an average US bushel weight of 27 kg (60 pounds) (Murphy 1993-2007), approximately 520 fanegas of wheat – or 20 percent the combined total wheat harvests of 1786, 1787, and 1788 (Mission Santa Clara *Informes*) – composed the walls of the Third Mission.

Time and Wage Discussion

To model the cost of the church, the author assumes that the total cost (C) is a function of the quantity of labor (L) required to build it. The quantity of labor used to construct the church is based on three variables: the quantity of bricks needed (q), the time (t) required by the natives to manufacture the bricks, and the daily wage (w) the natives would have received for their efforts (had they been paid). Stated mathematically, the equation for modeling the cost to manufacture the adobe bricks is C=L(q,t,w). With the dimensions of the church defined and the average brick size estimated, the last variables to address are the manufacturing time and the "wage."

According to church records it took two and a half years to complete the Third Mission, from November 19, 1781 to the dedication of the church on May 16, 1784 (Spearman 1963:33). In terms of labor production, Fray Estevan Tapis stated nine Natives made 40 adobe bricks a day per person, and this work never occurred after 11 a.m., nor on Saturdays

or Sundays, and often not Fridays, as the weekly task was normally completed by then (Engelhardt 1930:577; Webb 1952:106). According to this schedule, each Native was responsible for producing 200 adobe bricks a week, and often the natives were able to complete this task in four days instead of the five allotted. While it is probable that this production rate fluctuated, and putting aside any potential bias and the passage of time, these are the only available figures concerning the production rate of adobe bricks during the Spanish Mission period.

The last step in the modeling process is to determine the "wage" paid to the Native Americans for their work on the church. Even though no actual monetary wage was paid out to these workers, the construction of the Third Mission church was not free. For the purposes of this analysis, it is assumed that if the Natives were not baptized into the Mission system and the Missionaries wanted to build a church, they would have needed to contract with laborers from somewhere else and paid a wage both parties deemed fair.

Since there are no "hard" data on wages paid to the natives, for this exercise a range of potential wages based on several accounts and scenarios are used. The lowest wage identified and used in this analysis was the rate the missionaries at Santa Barbara in the early 1800s received when they contracted out native workers to the Presidio of Santa Barbara (Duggan, personal communication 2004). According to the Mission Santa Barbara accounts, a "Normal Chumash Male Laborer" was hired out to the Presidio at a rate of one and a half reales per day. For comparison, according to Schuetz-Miller (1994:19), five reales a day were paid to a "competent journeyman" in Mexico City to work in California, and 18 reales a day – the highest wage in the range – was paid to the highest-paid contracted master mason and stone cutter in Mexico City to work in California.

This range provides an important gauge in economic modeling. If the analysis shows that at the lowest wage identified the brick manufacturing costs significantly outweighed the value of the Mission's agricultural assets, then it seems highly doubtful that the total costs to construct the Mission were ever recouped. At the opposite end of the spectrum, if the costs of brick making at the highest wage identified was quickly recovered by the Mission's agricultural output, then it is possible – perhaps even probable – that building the Mission was a financially sound decision.

Brick Manufacturing Costs and Financial Implications

Using the assumptions and the data provided, based on the estimated 80,000 bricks necessary to construct the walls, at the lowest wage in the range (1.5 reales/day) the missionaries would have spent 3,000 reales to manufacture the bricks, at an average cost of 0.04 reales per brick. At 5 reales/day the costs would increase to 10,000 reales with an average cost of 0.13 reales per brick. At the highest wage – or 18 reales/day – the costs to manufacture the bricks escalate to 36,000 reales with an average cost per brick of 0.45 reales. Table 1 provides brick manufacturing costs based on 10 different wage rates.

Table 1. The Total Cost to Manufacture 80,000 Bricks Range from 3,000 Reales Based on a 1.5 Reales/Day Wage to 36,000 Reales Based on an 18 Reales/Day Wage

Wage (Reales/Day)	Total Costs (Reales)	Avg Cost/Brick (Reales)
1.5	3,000	0.04
3	6,000	0.08
5	10,000	0.13
6	12,000	0.15
7	14,000	0.18
10	19,900	0.25
12	23,000	0.30
14	28,000	0.35
16	31,800	0.40
18	36,000	0.45

Profit and Loss Analysis

To estimate financial viability, a profit-and-loss statement for the Mission was constructed for the years 1786 through 1788, where the value of the Mission's agricultural assets was compared with the amortized costs of manufacturing the bricks and feeding the Mission congregation. The agricultural assets included all grain types harvested and all livestock varieties reported during the period in the Mission *Informes*, and valued based on the regulated agricultural prices at the time (Mosk 1938:119). The cost of feeding the resident Native population was based on an estimated required subsistence of four fanegas of wheat per person per year (Jackson and Castillo 1995:46). The purpose of this variable is to determine whether the Mission had the resources available to provide a fixed level of food to the congregation and remain a profitable entity. The years 1786, 1787, and 1788 were used for this analysis, as they were the earliest records located for the Third Mission. One final note, the annual stipend (Duggan 2000:220) received by each Mission from the Spanish authorities was removed from this analysis, to see if the Mission as a financial venture was able to "stand on its own two feet" without requiring external funding.

Table 2 depicts the financial results based on wages of one and a half, five, and 18 reales per day. An analysis of the profit-and-loss statement shows that the only occasion where the costs would have outweighed the value of the Mission's agricultural assets is in 1786, and only when the daily wage

Table 2. Brick Manufacturing Costs Amortized over a Three-year Period and Compared with the Mission's Agricultural Assets

Assumptions				
	Wage (Reales/Day)	1.5	5	18
	Total Brick Costs	3,000	10,000	36,000
1786				
	Costs			
	3 yr Amortized Brick Costs	1,000	3,333	12,000
	Wheat for Consumption (557 people, 4 fanegas per person/yr)	35,648	35,648	35,648
	Total Costs	*36,648*	*38,981*	*47,648*
	Agricultural Production			
	Grain Harvest	9,355	9,355	9,355
	Livestock	34,128	34,128	34,128
	Total Value	*43,483*	*43,483*	*43,483*
	Net Value - 1786	***6,835***	***4,501***	***(4,165)***
1787				
	Costs			
	3 yr Amortized Brick Costs	1,000	3,333	12,000
	Wheat for Consumption (647 people, 4 fanegas per person/yr)	41,408	41,408	41,408
	Total Costs	*42,408*	*44,741*	*53,408*
	Agricultural Production			
	Grain Harvest	28,784	28,784	28,784
	Livestock	67,724	67,724	67,724
	Total Value	96,508	96,508	96,508
	Net Value - 1787	***54,100***	***51,767***	***43,100***
1788				
	Costs			
	3 yr Amortized Brick Costs	1,000	3,333	12,000
	Wheat for Consumption (672 people, 4 fanegas per person/yr)	43,008	43,008	43,008
	Total Costs	*44,008*	*46,341*	*55,008*
	Agricultural Production			
	Grain Harvest	29,968	29,968	29,968
	Livestock	79,590	79,590	79,590
	Total Value	*109,558*	*109,558*	*109,558*
	Net Value - 1788	***65,550***	***63,217***	***54,550***
Three Year Summary				
	Total Costs – 3 Years	123,100	130,100	156,100
	Total Value – 3 Years	249,500	249,500	249,500
	Net Value – 3 Years	***126,400***	***119,400***	***93,400***
	Percent Return – 3 Years	***202.7%***	***191.8%***	***159.8%***

Note: the costs of supporting the mission's congregation are included based on an average subsistence of four fanegas of wheat per person, per year.

paid to the natives exceeds 12 reales per day. Otherwise, over the course of the three-year period the missionaries realized a 160-200 percent return on their investment. While the total costs per year – due to the growth in population - increased at a compound annual growth rate (CAGR) of 7.5 percent, the value of the Mission's agricultural assets – particularly the cattle stock – increased rapidly at a CAGR of 58.7 percent over the same period.

In all three years, the value of the Mission's wheat harvest was significantly lower than the four fanegas per person per year required for sustaining the resident population. For example, the 1786 wheat harvest accounted for only 26 percent the total quantity of wheat required to feed the congregation. When combined with the value of the Mission's livestock, however, the total agricultural assets of the Third Mission were adequate to fund the Third Mission's food requirements. Additionally, the natives were almost certainly fed more than grain - the quantity of butchered cattle bone in Mission-era archaeological deposits demonstrates that more than wheat was consumed at Mission Santa Clara (Hylkema 2000, 2000-2002; Garlinghouse, this volume).

When the financial results are charted (Figure 2), it appears qualitatively that by the fourth year after its dedication date, the Third Santa Clara Mission may have been a successful and profitable endeavor. Additional research is required to fully prove this theory.

Conclusions and Additional Research

Manufacturing 80,000 bricks for the Third Mission Santa Clara was clearly a monumental task, yet using economic and financial tools, it can be shown that the Mission recouped its brick manufacturing costs in a little over a year. With brick production likely one of the most expensive efforts in constructing the Mission, pending further research, these findings indicate that the Third Santa Clara Mission was financially successful.

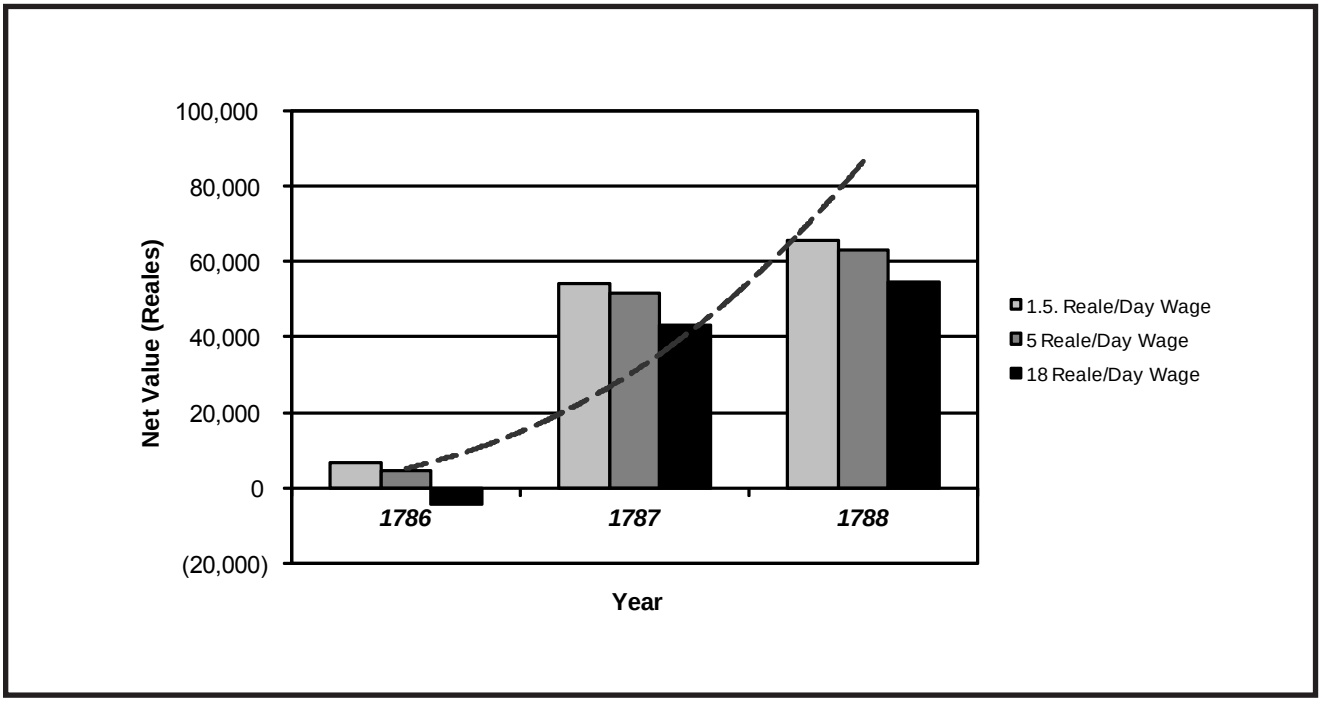

Figure 2. The costs of brick manufacturing and feeding the congregation are subtracted from the agricultural assets to ascertain the Third Mission Santa Clara's net value. During this period, only in 1786 at wages greater than 12 reales/day does the mission realize a net loss.

Additional analyses by the author on the construction of the footings, bricklaying, roofing, etc., are under way and likely to yield additional insights into the profitability of the Mission. Concurrently, the Third Mission profit-and-loss statement is being expanded by the author to incorporate a wider date range for comparing the construction costs with the Mission's agricultural assets.

Finally, the approach and model discussed in this paper can be adapted and employed for estimating the productivity and financial viability of any adobe-based mission in California. It is the author's vision to expand this research to as many adobe-based missions as possible to identify the financially profitable and unprofitable missions, and see if in aggregate there was a financial justification for the establishment of the entire mission system.

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