Designing Water Self-Sustaining International Projects Using Comprehensive Water Auditing

Courtney Crosson
University of Arizona, Tucson, Arizona

ABSTRACT: *Moyo Community Health Center is a five-acre campus in Moyo, Uganda that currently receives water for its clinics from a neighboring private well and energy from an existing photovoltaic array. With two prominent rainy seasons, Moyo receives over 20 inches of rainfall each year. This paper investigates the potential for rural health centers with limited water supply to become water self-sustaining through rainwater collection, treatment, and use. A group of fifteen architecture; architectural engineering; and water, society, policy students engaged in a semester-long project to complete a water audit for the health center in Moyo from their classroom in Arizona. The audit was comprised of four modules focused on conservation, passive measures, active measures, and process water. Three rounds of community engagement virtual activities with the health center and a supporting non-governmental organization, Pipeline Worldwide, were conducted to obtain building and fixture measurements, occupancy numbers, typical uses, landscape species specifications, and system details from the site. The audit culminated in an integrated net zero water design for the health center. This paper lays out a method for engaging with an international and rural community partner at a distance to offer water auditing services. Overall, Moyo Mission Health Center's baseline water demand was 570,236 gallons each year. Applying conservation and passive measures, the demand dropped to 376,407 gallons each year. Rainwater harvesting systems with appropriately sized cisterns were designed based on the daily rainfall and existing ten buildings' roof areas and runoff coefficients to meet this 376,407 gallon demand. The paper concludes that this work is possible with committed and communicative community partners and a clearly structured auditing process. The results from the water audit are presented to illustrate this process. The paper concludes with a discussion of ethical concerns and mutual benefits from the international engagement. As an outcome to the audit and net zero water design, the health center is receiving funding from Pipeline Worldwide to install large cisterns to achieve the self-sustaining water balance.*

KEYWORDS: net zero water, international partnerships, rainwater harvesting, rural, auditing

INTRODUCTION

Rural projects that exist separate from centralized water infrastructure rely on a fine balance between naturally provided sources of water, storage capacities, and annual demands. To ensure a reliable supply of water, accuracy is important when designing such self-sustaining systems to achieve a net zero water balance in the course of a year. University architecture courses that teach students water auditing skills have the resources to provide auditing services in such conditions. This project was a partnership between a University of Arizona course, Moyo Mission Health Centre in rural Uganda, and the non-governmental organization Pipeline Worldwide. Moyo Mission Health Centre currently relies on a neighboring well for water, but would like to be able to operate independent of this neighborly dependence. The students in the course completed a comprehensive water audit to provide the rural health centre with the volume of cistern(s) necessary to reach a self-sustaining water system with rainwater catchment from the ten buildings on campus. The audit consisted of four modules: conservation, passive systems, active systems, and integrated strategy implementation. The audit and resulting design determined that with correctly sized underground storage cistern(s), Moyo Mission Health Centre could realize a self-sustaining or net zero water system.

This paper investigates the ability for water audits to be done virtually to support international partners in rural conditions. It uses the case study of Moyo Mission Health Centre to assess this potential. The paper starts with a literature review and explanation of background of the case study site. Then, the methodology of the four module water auditing process is outlined. Moyo Mission Health Centre is used to illustrate this process and provide results from the audit work. The findings from the auditing process and resulting design of the self-sustaining net zero water system are presented and analyzed. The ethical challenges and larger benefits to both sides of the international service-learning partnership are discussed. The paper concludes that international partnerships between a university building technology course and a real-world client can be powerful opportunities to provide students with tangible applications for their learning and a partner in need with an important service. Virtual technologies can be a cost-effective way to achieve these outcomes without costly and carbon intensive travel. Pipeline Worldwide has pledged to fund the sized cistern to implement the net zero design for Moyo Mission Health Centre.

1. BACHGROUND AND LITERATURE REVIEW

1.1 Water infrastructure in Moyo Uganda

Moyo Mission Health Center is located outside Moyo town in the north of Uganda on the Sudanese border (Figure 1). Given this location, in addition to Ugandan citizens, there is a large population of refugees from Sudan and central African countries that are serviced by the health centre. In the 2020 Ugandan census, the population was about 12,000 residents in Moyo town and 109,500 residents in the wider Moyo District (City Population, 2023). The town of Moyo is serviced by electricity, water and sanitation. However, the Moyo Water Supply and Sanitation System do not extend these water services outside the town. Thus, facilities like the Moyo Mission Health Centre that sit outside servicing areas need to provide their own power, water, and sanitation services. Currently, the centre receives its power from onsite photovoltaic cells. Water is supplied from a borehole from a neighboring parish (Figure 1). An onsite septic system and leech field for flush toilets with a series of independent compost toilets provide sanitation services. The centre's goal is to no longer depend on the neighboring parish and become water self-sufficient through onsite rainwater catchment from Moyo's two rainy seasons on the centre's ten building roofs.

1.2 Exisiting status of Moyo mission health centre

Uganda's health facilities are classified into seven levels based on the services they provide. Moyo Mission Health Centre is a level IV center. In order to move to the next level, Moyo Mission Health Centre needs a reliable source of water and power, which they current do not have. A self-sustaining water system would help the centre to service more people with a broader set of abilities – such as surgery that goes beyond child delivery. Pipeline Worldwide reached out to University of Arizona School of Architecture as Pipeline's main office is in Phoenix, Arizona. Pipeline Worldwide met officials at the health centre during a recent visit to Moyo in 2021 and identified the needs of the center, then connected them with the capabilities of the University of Arizona Water Efficiency course to conduct a water audit and calculate the necessary cistern sizes to reach water self-sufficiency for the campus.

Figure 1: Moyo Mission Health Centre Campus and Existing Water Supply. Source: (Author 2021)

1.3 Passive and active rainwater harvesting and rural applications

This research modeled an integrated system of passive and active rainwater harvesting to meet the calculated demands of Moyo Mission Health Centre. By definition, passive rainwater systems are designed to retain water until it can be naturally absorbed into the land (swales and pervious pavers are common passive strategies) and do not require energy to function. Active systems, by comparison, collect, clean, and store rainwater for use (tanks and cisterns are prevalent elements of active harvesting). Water harvested passively offsets irrigation demands, whereas water harvested through active systems can be stored and employed to meet non-potable and potable demands, depending on the treatment level achieved. The main design parameters of active rainwater harvesting systems are rainfall volume, catchment area, tank volume, and water demand. Passive systems have the same design parameters, excluding tank volume. These parameters all dictate system efficiency, though rainfall and water demand have been shown to have the largest effect (Mun and Han, 2012). Active rainwater harvesting has been increasingly implemented in areas that face growing water constraints under climatic, environmental, and social changes (Amos et al., 2016). Active system implementations have traditionally centered on irrigation demands, especially in the US (Gao et al., 2016). However, recent literature looks at implementations across countries in Asia, Australia, Africa, and Europe for toilet flushing and other domestic uses (Furumai, 2008). By comparison, passive rainwater harvesting has focused on stormwater mitigation. Passive strategies have featured prominently in literature on Low Impact Development or Sustainable Drainage System approaches (Hamel and Fletcher, 2014).

2. METHOD

The water audit methodology was comprised of four modules: (1) conservation, (2) passive systems, (3) active systems, and (4) integrated strategy implementation (TABLE 1). Each of the first three modules were composed of a baseline assessment, a quantitative and qualitative auditing process, and strategy recommendations. In the fourth module, a comprehensive strategy implementation plan was provided to the health centre and Pipeline Worldwide. Students devised comprehensive strategies to reduce indoor and outdoor building water use together to decrease demand such that a self-sufficiency or net zero state could be achieved. Before the water audit began, it was important to solidify expectations between the three partners in a Memorandum of Understanding. The next sections outline these steps and the results in the Moyo Mission Health Centre case study.

Table 1: Four Module Water Auditing Process. Source: (Author 2023)

Module	Time	Focus of Audit	Design Application
Module 1	Month 1	Indoor Water Use	Conservation Design
Module 2	Month 2	Outdoor Water Use	Passive Design
Module 3	Month 3	Process Water Use	Active Design
Module 4	Month 4	Integrated Strategies	Technology and Energy-Water Nexus

2.1 Community engagement and memorandum of understanding

A Memorandum of Understanding was formed between the Water Efficiency in Buildings course (ARCH 461/561), Pipeline Worldwide, and Moyo Mission Health Centre. Pipeline Worldwide first reached out to the University of Arizona School of Architecture and identified the necessary water auditing work during their most recent trip prior to the MOU. The MOU laid out the basic expectation from all involved parties in supplying data, conducting interviews by students during the semester, and the ultimate deliverable that would be provided by the course in the form of a final recorded presentation accompanied by a printed version. Pipeline Worldwide has partnered with several University of Arizona courses and courses from other universities. Pipeline Worldwide calls themselves “a conduit for facilitating connections between donors and vulnerable communities in East Africa, based on the needs voiced by local leaders. Pipeline Worldwide provides funding, time and resources for projects that deliver access to clean water, sanitation, education, healthcare, and development in the region’s most impoverished communities (Pipeline Worldwide, 2022).” In the case of the water audit and University of Arizona course, Pipeline Worldwide was the conduit for connecting resources and the future funder of the cisterns needed to reach a self-sustaining rainwater harvesting system. The University of Arizona course was comprised of fifteen architecture; architectural engineering; and water, society, policy students engaged in the semester-long project to complete a water audit for the health center in Moyo.

2.2 Auditing module 1: conservation

The first step of the water auditing protocol was to establish a baseline use by which future efficiency gains could be measured. The baseline contained both quantitative numbers and qualitative behaviors. In the first month of the course, information was provided by Moyo Mission Health Centre used to calculate overall water demand from the number and type of fixtures and the number and type of building occupants across the ten buildings (FIGURE 2). Occupancy was specified across the ten buildings, so that each rainwater catchment area had an exact linked water demand calculated, in case a modular design of many cisterns was favored.

Full-time equivalency factions (FTE) were applied to doctors and staff that worked partial days or additional hours past the assume 1.0 FTE for an eight-hour workday. Assumptions of water use per FTE were based on standards taken from the Leadership in Energy and Environmental Design (LEED) Water Efficiency credits that are linked to data from the most recent version of the Environmental Protection Act. The main learning objective during the baseline step is for students to understand how to measure each type of fixture use, average user behaviors by fixture use, and the impact of basic conservation measures.

Results from Moyo Mission Health Centre: Indoor water use was calculated for each of the ten buildings with this occupancy, use behavior, and fixture data. Bathroom sinks, laundry sinks, kitchen sinks, flush toilets, compost toilets, showers, and outdoor water taps for maintenance and laundry were the fixtures specified in these calculations. Students used baseline assumptions of the fixtures currently in place and then suggested more efficient fixtures in their conservation strategy implementation. Total percentage reductions are calculated between baseline and potential reduction. An expansion of compost toilets, lower flow shower heads, aerators for hand washing sinks, and higher efficiency toilets were suggested as conservation implementations. With these conservation strategies, an overall 33.5% water savings was calculated from a current 570,236 gallon annual campus baseline to a 379,263 gallon annual use target (Figure 2).

	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6	Building 7	Building 8	Building 9	Building 10
January	7,815.72	1,473.12	4,352.40	8,583.90	6,172.10	4,956.90	7,130.00	1,432.20	682.00	3,831.60
February	7,059.36	1,330.56	3,931.20	7,753.20	5,574.80	4,477.20	6,440.00	1,293.60	616.00	3,460.80
March	7,815.72	1,473.12	4,352.40	8,583.90	6,172.10	4,956.90	7,130.00	1,432.20	682.00	3,831.60
April	7,563.60	1,425.60	4,212.00	8,307.00	5,973.00	4,797.00	6,900.00	1,386.00	660.00	3,708.00
May	7,815.72	1,473.12	4,352.40	8,583.90	6,172.10	4,956.90	7,130.00	1,432.20	682.00	3,831.60
June	7,563.60	1,425.60	4,212.00	8,307.00	5,973.00	4,797.00	6,900.00	1,386.00	660.00	3,708.00
July	7,815.72	1,473.12	4,352.40	8,583.90	6,172.10	4,956.90	7,130.00	1,432.20	682.00	3,831.60
August	9,247.92	1,677.72	4,956.90	11,001.90	7,365.60	5,561.40	7,905.00	1,466.30	716.10	4,470.20
September	8,949.60	1,623.60	4,797.00	10,647.00	7,128.00	5,382.00	7,650.00	1,419.00	693.00	4,326.00
October	9,247.92	1,677.72	4,956.90	11,001.90	7,365.60	5,561.40	7,905.00	1,466.30	716.10	4,470.20
November	7,563.60	1,425.60	4,212.00	8,307.00	5,973.00	4,797.00	6,900.00	1,386.00	660.00	3,708.00
December	7,815.72	1,473.12	4,352.40	8,583.90	6,172.10	4,956.90	7,130.00	1,432.20	682.00	3,831.60
Annually	96,274.20	17,952.00	53,040.00	108,244.50	76,213.50	60,157.50	86,250.00	16,964.20	8,131.20	47,009.20

	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6	Building 7	Building 8	Building 9	Building 10
January	5328.9	1004.4	3158.28	6228.83	4208.25	3,342.73	3,750.38	976.5	465	2585.4
February	4813.2	907.2	2852.64	5626.04	3801	3,019.24	3,387.44	882	420	2335.2
March	5328.9	1004.4	3158.28	6228.83	4208.25	3,342.73	3,750.38	976.5	465	2585.4
April	5157	972	3056.4	6027.9	4072.5	3,234.90	3,629.40	945	450	2502
May	5328.9	1004.4	3158.28	6228.83	4208.25	3,342.73	3,750.38	976.5	465	2585.4
June	5157	972	3056.4	6027.9	4072.5	3,234.90	3,629.40	945	450	2502
July	5328.9	1004.4	3158.28	6228.83	4208.25	3,342.73	3,750.38	976.5	465	2585.4
August	6305.4	1143.9	3596.93	7487.43	5022	3,443.48	4,158.03	999.75	488.25	3016.3
September	6102	1107	3480.9	7245.9	4860	3,332.40	4,023.90	967.5	472.5	2919
October	6305.4	1143.9	3596.93	7487.43	5022	3,443.48	4,158.03	999.75	488.25	3016.3
November	5157	972	3056.4	6027.9	4072.5	3,234.90	3,629.40	945	450	2502
December	5328.9	1004.4	3158.28	6228.83	4208.25	3,342.73	3,750.38	976.5	465	2585.4
Annually	65,641.50	12,240.00	38,488.00	77,074.65	51,963.75	39,656.95	45,367.50	11,566.50	5,544.00	31,719.80

Current	570,236.30
Ambition	379,262.65
Percentage of Savings	33.49%

Figure 2: All numbers in gallons. Moyo Mission Health Centre Campus Current Water Demand (above) and Projected Water Savings with Implementation of Conservation Strategies (below). Source: (students of ARC 461/561 Spring 2021 with Author 2021)

2.3 Auditing module 2: passive systems

In the second month of the course, students completed a site water audit for outdoor uses and consider passive measures to increase efficiency of outdoor water use. The site also had significant flooding issues in areas. Passive rainwater harvesting strategies were designed to reorient water circulation so that flooding was reduced and water was more efficiently used to meet outdoor demands over time.

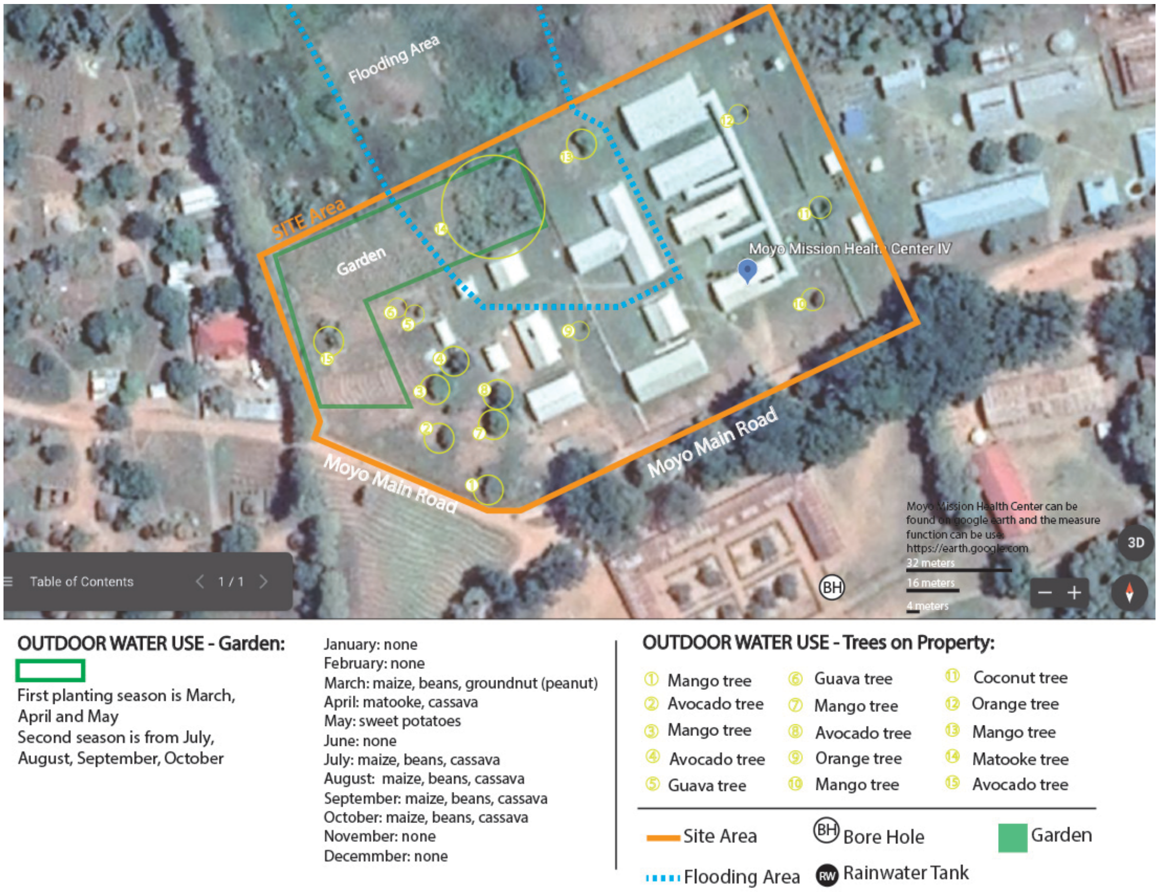

Figure 3: Moyo Mission Health Centre Campus with Outdoor Water Needs. Source: (Author 2021)

<u>Results from Moyo Mission Health Centre:</u> For this module, students complete a site plan, locating various vegetation species throughout the site (FIGURE 3). To calculate outdoor water demand, the students then used species factors, microclimate factors, and density factors to project vegetation demand. To calculate potential new sources of water (through passive strategies), students then used the site plan, average monthly precipitation, and various pervious material run-off coefficients to calculate possible water collection volumes. Students consider both passive rainwater harvesting, reduction of turf grass, and native and adaptive species as strategies to passively reduce water use outdoors or more efficiently use natural rainfall. Students completed a water budget for outside supply and demand. The total annual passive rainwater supply on the health centre campus was computed to average 4,535,564 gallons a year. Students treated the garden water use for campus-sustaining food production as separate as the landscape beautification of the campus grounds. Students then designed a passive strategies master plan where swales with strategically placed water absorbing vegetation and raised walkways made better use of the natural rainfall, allowed for water to be slowed and circulated throughout the site, and also decreased chronic areas of campus flooding.

2.4 Auditing module 3: active systems

In the third month of the course, students considered active rainwater harvesting as means to achieve self-sufficiency based on the calculations in Module 1 and 2. Typically, active systems to decrease potable water use include rainwater harvesting, gray water use, and condensate recovery. However, in this healthcare and rural Uganda situation, the only applicable active measure was active rainwater harvesting. Graywater harvesting is deemed impermissible in healthcare settings where there is significant disease, bodily fluids, and public health concerns. There were no air-conditioning units, thus no opportunities for condensate recovery.

An array of modelling tools and methods to design and evaluate RWH systems have been developed over the last several decades. As rainfall and water demand are both temporally and spatially variable, models for active RWH have predominantly focused on calculating the volume of storage required to balance these inflows and outflows for a specific location (Campisiano et al., 2017). Tank size design has been computed with various methodologies. Approaches include the use of empirical relationships (Ghisi, 2010; Palla et al., 2011), stochastic analysis (Cowden et al, 2008; Basinger et al., 2010), and continuous mass-balance simulations of the tank inflow and outflow (Fewkes and Butler, 2000; Liaw and Tsai, 2004; Campisano and Modica, 2015). Mass-balance models combine the localized rainfall and water demand at a variety of spatial and temporal scales (Campisano and Modica, 2015; Melville-Shreeve et al., 2016). These models have also been used to simulate systems under uncertain climatic shifts (Mitchell, 2007; Lash et al., 2014). Several studies have found that aligning water demands closely with local rainfall patterns significantly increases system efficiency (Zhang et al., 2009). In the case of this water audit performed by students, a mass-balance method was used over monthly periods. Although this is much less accurate than the preferred daily mass-balance approach, this rougher calculation was adequate for the reasonable tolerance for error in the cistern design and the other auditing calculations.

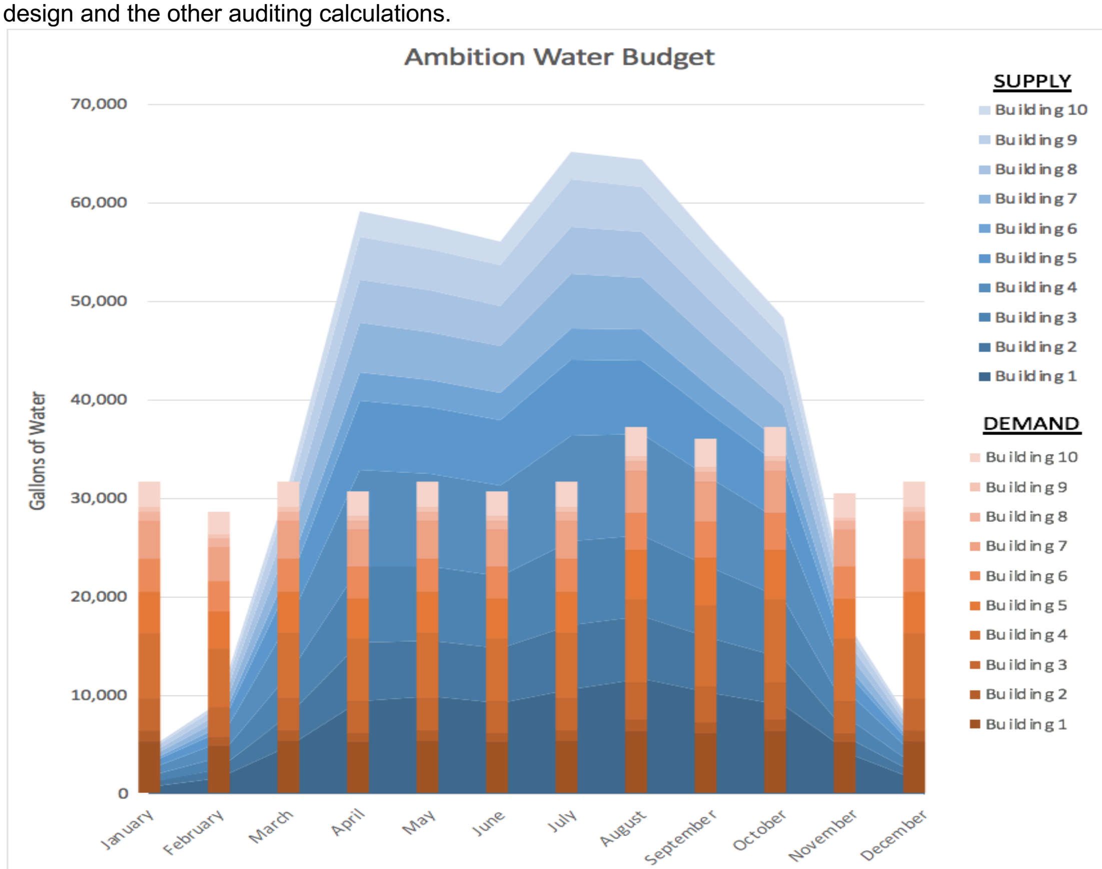

Figure 4: Moyo Mission Health Centre Campus Final Self-Sustaining Water Budget with Outcomes of Four Module Audit and Implementations. Source: (students of ARC 461/561 Spring 2021 with Author 2021)

Results from Moyo Mission Health Centre: Students calculated the total rainwater that could be harvested from each of the roofs from the ten buildings. The students created an overall water budget based on the data from Modules 1, 2, and 3 (Figure 4). Then the water budget is used to size the necessary cistern(s) to lead to a water self-sustaining status. From the calculated indoor demands from this budget, students then ran the monthly mass-balance calculations for active rainwater catchment design for (1) each building having its own cistern and (2) implementing two large underground cisterns that were connected and serviced all buildings as a connected campus water system. From this water budget and the two cistern design proposals, a total potential reduction is calculated. In Figure 4, the blue supply that is exceeded in rainy months is stored in the designed cistern system and used when there is an absence of supply, but still a steady demand (i.e. January, February, November, and December). It was determined for the purposes of overall system resilience and cost; it was better to build the two large underground cisterns and tie buildings together in one water system. A total 29,000 gallon storage capacity for the entire campus was computed to achieve a self-sustaining or net zero water system.

2.5 Auditing module 4: integration of strategies

In the final month of the audit, students looked holistically at data and recommendations from Module 1, 2, and 3. In Module 4, students also added research on new technologies that had also been shown to be successful and could be helpful to further the water goals of the project. In the case of Moyo Mission Health Centre, this included treatment options for the collected rainwater and permeable paving technologies for parking surfaces and erosion control. Students completed a full report for final presentation to Moyo Mission Health Centrer and Pipeline Worldwide that was both live and recorded and provided to the international partners.

Results from Moyo Mission Health Centre: Overall, Moyo Mission Health Center's baseline water demand was 570,236 gallons each year. Applying conservation and passive measures, the demand dropped to 376,407 gallons each year. Passive strategies also decreased areas of significant flooding onsite. Active rainwater harvesting systems with appropriately sized cisterns were designed based on the monthly rainfall and existing ten buildings' roof areas and runoff coefficients to meet this 376,407 gallon demand with two cisterns of 29,000 gallons total capacity.

3. DISCUSSION

3.1 International partnerships: a net gain?

International partnerships can be challenging, logistically and ethically. Communication can be difficult due to time zone constraints and cultural differences. Students' ability to fully understand place specific conditions may be limited by never having experienced the location and their own biases from more narrow lived experience. The design of solutions to site specific challenges may be misguided by holes in understanding of local materials, maintenance capacities, and local assumptions about use. Thus, in these partnerships, it is critical to have a strong local partner that can effectively communicate local circumstances and needs and have the buy-in necessary for the long-term maintenance of any design implemented. It is also necessary that students are able to push themselves to stay open, challenge biases and assumptions, listen carefully, and ask good questions when they humbly do not understand. Overall, despite these challenges, international partnerships can be important opportunities to stretch student understanding, student ability to apply concepts and methods to a variety of situations and provide a breadth of perspective. Based on the case study of Moyo Mission Health Centre, the virtual water audit was a net gain both to student learning and application of that learning and the services needed by the international partners that resulted in concrete results.

3.1 Future steps: a self-sustaining net zero water Moyo mission health centre

Moyo Mission Health Centre is expecting the installation of two large underground cisterns as designed by the Water Efficiency in Buildings course (ARCH 461/561) course and sponsored by Pipeline Worldwide. This will support the centre in having its own functioning, self-sustaining water system, potentially leading to its approval as a next level health centre able to conduct surgeries beyond child delivery. Pipeline Worldwide has long standing work and partnerships in Moyo, thus Pipeline Worldwide will aid in the maintenance and long-term success of the new water system. Given the University of Arizona multiyear partnership with Pipeline Worldwide in several courses at the School of Architecture, the author looks forward to staying in touch with the organization and receiving feedback on the functioning of the system.

CONCLUSION

This paper argues that the resources of students in university courses can be connected to international development projects to provide comprehensive water audits using virtual technology. The audit was composed of four modules: (1) conservation, (2) passive design, (3) active design, and (4) holistic strategy implementation to reach a net zero status. In the case of Moyo Mission Health Centre, the audit successfully sized and designed the cisterns necessary to support reaching a self-sustaining status. Students benefited from the direct application of their water auditing knowledge, stretching their understanding of various applications of the water audit to a rural condition in a country with which students were not previously familiar, and the community partners benefited from the service and deliverables.

Architects need to receive training in school to design for a water efficient future. The auditing protocol provides architecture students (and other engaged students such as architectural engineering students) with a systematic tool to apply to each future building they design – whether in urban or rural conditions. The real-world experience of auditing for an actual project with funding for construction developed students' confidence to take on current and future challenges of water with an integrated process of measurement, analysis, and design. Net Zero Water is an important concept for architecture students to learn and have confidence in computing and implementing for the future of our increasingly water stressed built environments (both in scarcity and abundance of water). The author looks forward to future partnerships to achieve similar outcomes both for students and for community partners.

ACKNOWLEDGEMENTS

The author thanks architecture; architectural engineering; and water, society, policy students of the Spring 2021 Water Efficiency in Buildings course (ARCH 461/561), Pipeline Worldwide, and the director and staff of the Moyo Mission Health Centre. Additional gratitude to cross curriculum colleagues in the Critical Practices research concentration at the time of this course: Altaf Engineer, Christopher Trumble, and Aletheia Ida.

REFERENCES

Amos, C., Rahman, A., & Mwangi Gathenya, J. (2016). Economic analysis and feasibility of RWH systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. Water, 8(4), 149.

Basinger, M., Montalto, F., & Lall, U. (2010). A RWH system reliability model based on nonparametric stochastic rainfall generator. Journal of Hydrology, 392(3-4), 105-118.

Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., ... & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation and future perspectives. Water research, 195-209.

Campisano, A., & Modica, C. (2015). Appropriate resolution timescale to evaluate water saving and retention potential of RWH for toilet flushing in single houses. Journal of Hydroinformatics, 17(3), 331-346.

City Population. “Moyo District.” https://www.citypopulation.de/en/uganda/admin/northern/029__moyo/ Accessed 9 January 2023.

Cowden, J. R., Watkins Jr, D. W., & Mihelcic, J. R. (2008). Stochastic rainfall modeling in West Africa: Parsimonious approaches for domestic RWH assessment. Journal of Hydrology, 361(1-2), 64-77.

Fewkes, A., & Butler, D. (2000). Simulating the performance of rainwater collection and reuse systems using behavioural models. Building Services Engineering Research and Technology, 21(2), 99-106.

Furumai, H. (2008). Rainwater and reclaimed wastewater for sustainable urban water use. Physics and Chemistry of the Earth, Parts A/B/C, 33(5), 340-346.

Ghisi, E. (2010). Parameters influencing the sizing of rainwater tanks for use in houses. Water Resources Management, 24(10), 2381-2403.

Hamel, P., & Fletcher, T. D. (2014). The impact of stormwater source-control strategies on the (low) flow regime of urban catchments. Water Science and Technology, 69(4), 739-745.

Lash, D., Ward, S., Kershaw, T., Butler, D., & Eames, M. (2014). Robust rainwater harvesting: Probabilistic tank sizing for climate change adaptation. Journal of Water and Climate Change, 5(4), 526-539.

Liaw, C. H., & Tsai, Y. L. (2004). Optimum storage volume of rooftop rain water harvesting systems for domestic use 1. JAWRA Journal of the American Water Resources Association, 40(4), 901-912.

Melville-Shreeve, P., Ward, S., & Butler, D. (2016). RWH typologies for UK houses: A multi criteria analysis of system configurations. Water, 8(4), 129.

Mitchell, V. G. (2007). How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling?. Hydrological Processes: An International Journal, 21(21), 2850-2861.

Palla, A., Gnecco, I., & Lanza, L. G. (2011). Non-dimensional design parameters and performance assessment of RWH systems. Journal of Hydrology, 401(1-2), 65-76.

Mun, J. S., & Han, M. Y. (2012). Design and operational parameters of a rooftop rainwater harvesting system: definition, sensitivity and verification. Journal of Environmental Management, 93(1), 147-153.

Pipeline Worldwide. “Pipeline Worldwide.” https://www.pipelineworldwide.org. Accessed 4 December 2022.

Zhang, Y., Chen, D., Chen, L., & Ashbolt, S. (2009). Potential for rainwater use in high-rise buildings in Australian cities. Journal of environmental management, 91(1), 222-226.