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BIOHEAL: TREE UPCYCLING FOR ARCHITECTURAL HEALING

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ABSTRACT:

Felled tree upcycling is crucial not only for reducing carbon emissions but also as a valuable renewable material in resource-scarce Singapore. The *BioHeal* project aims to pilot test the challenges and opportunities of tree upcycling for a rapidly aging population, with the goal of aiding faster patient recovery through biophilic architectural installations of upcycled timber at a public hospital extension project. To preserve the public's fond memories of its natural environment and historical importance, it is required to install upcycled timber sourced only from the designated construction site within the campus.

A *Tree-to-Design* approach (as opposed to the typical "Designs come first" process), born out of necessity, was developed to address the limited and unpredictable supply of species, sizes, and quantities of upcycled timber. This approach maximizes the potential and highlights the uniqueness of upcycled trees as biophilic design features. These features include: 1. Sequential live edge partitions, 2. CNC-carved biomorphic columns, and 3. Mass-customized modular feature walls representing the diversity of the tropical timber species upcycled.

To promote the use of felled trees for commercial construction practices, it is recommended to establish a common public stockyard for upcycling trees. This would buffer the irregular but significant constant supply of felled trees from roadsides and construction site clearings, enabling clients and contractors to integrate upcycled timber into their practices in a more controlled and predictable manner, ensuring a sustainable and resource-efficient construction industry.

KEYWORDS: Biophilic, Healthcare, Upcycling, Sustainability, Tropical Trees.

1 – INTRODUCTION

1.1 *GARDEN CITY* TO *CITY IN NATURE*

In 1967 the Singapore government introduced a *Garden City* concept and began large-scale planting of roadside trees, followed in the mid-1970s by the creation of parks to meet the recreational needs of an increasingly affluent society. [1] Forests protection, reforestation and afforestation programmes play crucial roles in mitigating impact of climate change. While the focus has been on natural forest ecosystems, tree planting in urban settings has also received increasing attention as a means to offset carbon emissions, reduce urban temperatures and energy consumption. [2]

To enhance the aesthetic effect of the roadside trees, various tree species were used. Initially, cotton tree (*Ceiba pentandra*), angsana, flame of the forest (*Delonix regia*), saga (*Adenanthera pavonina*) and cassia (*Cassia fistula*) were planted extensively during the early decades of roadside tree planting. From the 1930s, other species including sea apple (*Syzygium grande*), bodhi (*Ficus religiosa*), tembusu (*Cyrtophyllum fragrans*), and rain tree (*Samanea saman*) were added to the mix. [1]

Despite being one of the most densely populated countries, Singapore boasts a Green View Index (GVI, MIT Senseable Lab) higher than most other cities. Notably, while Oslo has a GVI close to that of Singapore, its population density is significantly lower [3]. This highlights Singapore's successful integration of greenery within its high-density urban landscape.

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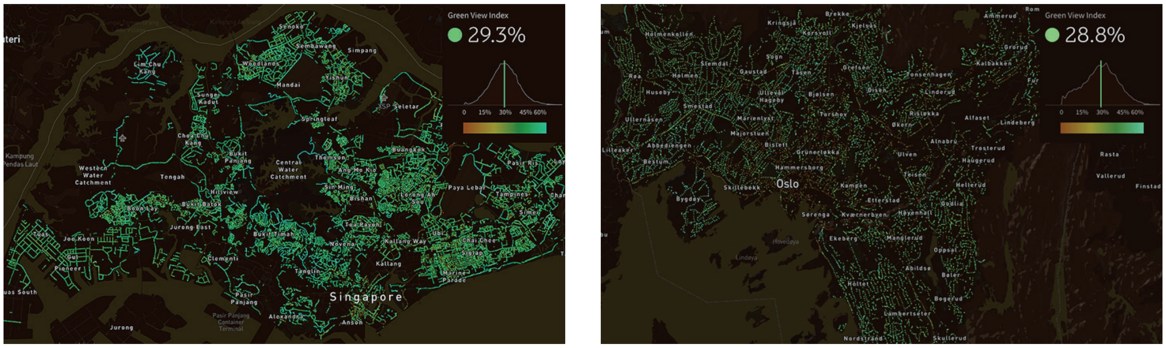

Figure 1. Green Visibility Index (GVI), Treepedia (2024), MIT senseable lab. Left: Singapore, GVI 29.3%, Population Density 7,797/km2. Right: Oslo, GVI 28.8%, Pupulation Density 4,421/km2. Singapore is one of the highest pupulation density in the world, yet to achieve the highest GVI. [3]

In 2020, the National Parks Board (NParks) announced the launch of *One Million Trees* movement as a key component of efforts to further extend nature into our urban landscape as we transform into a *City in Nature*. This will take place throughout the island, including streetscapes, gardens, parks and park connectors, nature reserves and nature parks, planting more than a million trees across Singapore, bringing the number of trees in Singapore from the current 7 million to more than 8 million over the next 10 years. [4]

1.2 ROADSIDE TREE FELLING

In 2022, *The Straits Times* reported that up to 13,000 trees will be felled over the next 13 years to make way for transport and housing projects. [5] The practice of replacing felled trees is not confined to those affected by parasites or diseases. The municipality also replaces trees that have been removed due to infrastructure projects such as the widening of roads, drain construction. [1] Prior to removal, NParks' arborists carry out professional assessments to decide if a tree can be saved or transplanted. [6]

Several initiatives are led by private companies to salvage these felled trees. For instance, a local sawmill tries to turn them into furniture [5], while a scrap company converts them into biomass products, such as organic fertilizers [7] The local sawmill commented that while these felled trees are readily available, they are more moist and require thorough drying before they can be cut. Additionally, these trees are complicated to work with, having grown under natural conditions compared to plantation timber. [5]

While the *One Million Tree* movement will significantly increase the standing tree stock in Singapore, the projected number of trees to be felled for various reasons will also rise. However, there are no reliable statistics on felled trees across the island available currently, nor is there a concerted framework to enable the utilization of these felled trees in the construction sector in Singapore.

1.3 BIOPHILIC DESIGNS FOR FASTER PATIENT RECOVERY

Singapore's population is aging rapidly, with nearly 1 in 5 citizens being 65 years or older in 2022. This demographic is expected to rise to about 23.8% by 2030. [8] The aging population is leading to a growing demand for inpatient care, coupled with insufficient manpower to staff hospital wards. The bed crunch at Singapore hospitals is becoming increasingly severe, resulting in some patients being stuck in emergency departments for prolonged periods. [9]

Given these circumstances, it is inevitable that there is a pressing need to support faster patient recovery to expedite discharge and alleviate bed shortages. Implementing biophilic design elements in healthcare environments has been shown to contribute significantly to patient well-being and recovery.[10] By integrating natural materials, such as upcycled timber, and incorporating design features that mimic natural patterns and forms, the *BioHeal* project aims to create a healing environment that promotes faster recovery.

2 – PROJECT DESCRIPTION

2.1 ALEXANDRA HOSPITAL'S TREE UPCYCLING INITIATIVE

Opened in 1940, Alexandra Hospital (AH), formerly the British Military Hospital, served as the principal hospital for Britain's Far East Command during World War II. Known as Singapore's first world-class healthcare facility, AH was the most advanced and best-equipped medical institution in Singapore and Malaya. [11]. AH is also renowned for its extensive greenery and serene environment, affectionately known as the "Hospital in a Garden". [12] To accommodate the construction of a new facility block named *Cocoon*, AH needed to clear part of its trees.

Figure 2. At the designated Cocoon building site, 25 trees with girths exceeding one meter were identified before construction began. Out of these, 17 trees were earmarked for timber harvesting and upcycling. Aside from the raintree, most of these species are exotic in architecture.
Left to Right: Raintree (Samanea saman), sea almond (Terminalia catappa), rosy trumpet (Tabebuia rosea), jambu (Syzygium grande) and bodhi tree (Ficus religiosa) at the Cocoon building site.

2.2 BIOPHILIC HEALING (*BIOHEAL*)

In 2022, AH engaged *SkyTimber*™, a tropical renewable architecture design lab at the National University of Singapore, to conduct a design-research project on the tree upcycling process and incorporate the upcycled timber into the features of the *Cocoon* building's rehabilitation centre - identifying and harvesting mature trees in the hospital grounds, before sawing them into timber and repurposing them as installations and furniture in the new rehabilitation centre. This initiative aimed to preserve the public's fond memories of AH's natural environment and historical importance.

At the designated *Cocoon* building site, 25 trees with girths exceeding one meter were identified before construction began. Out of these, 17 trees were earmarked for timber harvesting and upcycling. The collection included nine raintrees, two jambu trees, two sea almond trees, two rosy trumpet trees, one rambutan tree, and one bodhi tree. Aside from the raintree, most of these species are exotic in architecture.[13]

The *Bioheal* project brings together biodiversity, vitality, and relaxation, aiming to aid in both the physiological and psychological aspects of patients' recovery. A unique *Tree-to-Design* approach was implemented to maximize the potential of each harvested tree, considering their diverse sizes, shapes, colors, and textures, resulting in the four uniquely designated installations.

2.3 TREE UPCYCLING PROCESS

According to a local sawmill, the processing of wood is a 5-step process:

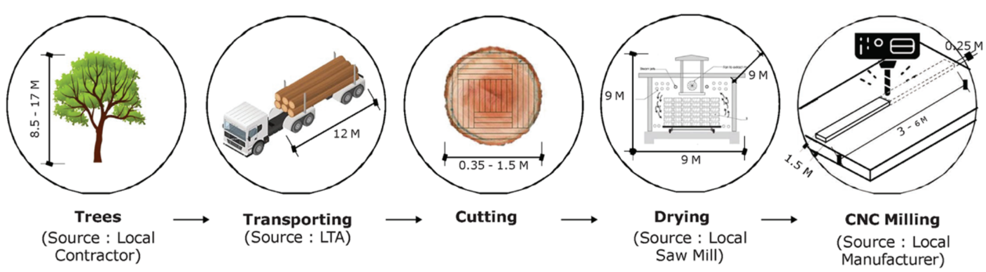

Figure 3. Dimensional constraints of tree upcycling processes. Initially, maximum length of logs is defined by transportaion process, while final timber element dimension is defined by CNC milling process.

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1) Debarking and Cutting – Removing the bark from the logs into fixed sizes.
2) Air Drying – Stacking of the cut lumber in a specific manner to promote efficient air circulation.
3) Kiln Drying – Used for faster drying in manner where it is more efficient in removing moisture. This ensures that the wood dries to be strong and durable.
4) Processing – End touches to the wood like varnishing, sanding, and treatment of wood for rotting.
5) Woodworking – The wood is then processed to the specifics of the design intention. [7]

A significant portion of the main stems of harvested tropical trees—often exceeding 50 percent—remains unused, with even higher losses reported in some cases. Timber harvesting recovery rates are notably low in Asia and the Pacific, averaging around 46 percent, compared to 54 percent in Africa, 56 percent in Latin America and the Caribbean, and 78 percent in the United States. Milling processes further reduce efficiency, with yields as low as 33 percent of the delivered log volume. A considerable body of evidence has shown that forest harvesting can result in substantial damage to the remaining stand, affecting up to 50 percent of residual trees (Sist et al., 1998), with some studies indicating rates as high as 60 percent in Sabah, Malaysia. The damage and loss of trees significantly contribute to logging residues. [14]

In industrial countries, a large share of logging and wood-processing residues is used by the pulp and wood-based panel industries. Alternatively, residues are chipped and burned by wood processors and power plants to produce steam and electricity.[14] At the *BioHeal* project, the AH determined to use the residues for souvenirs, such as wooden coasters and surrounding landscape elements.

2.4 *TREE-TO-DESIGN* APPROACH (NOT "DESIGN COMES FIRST")

In commercial practice, architects typically define designs based on clients' needs while considering commercially available material dimensions, such as standardized dimensions for plywood and other building materials. However, the *BioHeal* project presented a unique challenge: the final available timber quantity, quality, and dimensions were uncertain until the tree upcycling process was completed. This uncertainty stemmed from the nature of naturally grown trees, which are not straight and uniform.

To address these challenges, we invented the *Tree-to-Design* approach. This method diverges from the conventional "Design comes first" approach by prioritizing the natural characteristics of the harvested trees in the design process. Instead of imposing predefined design constraints, this approach seeks to:

Maximize Timber Dimensions
Utilize the maximum width and length of the logs harvested, considering the natural curvature and irregularities of the trees.

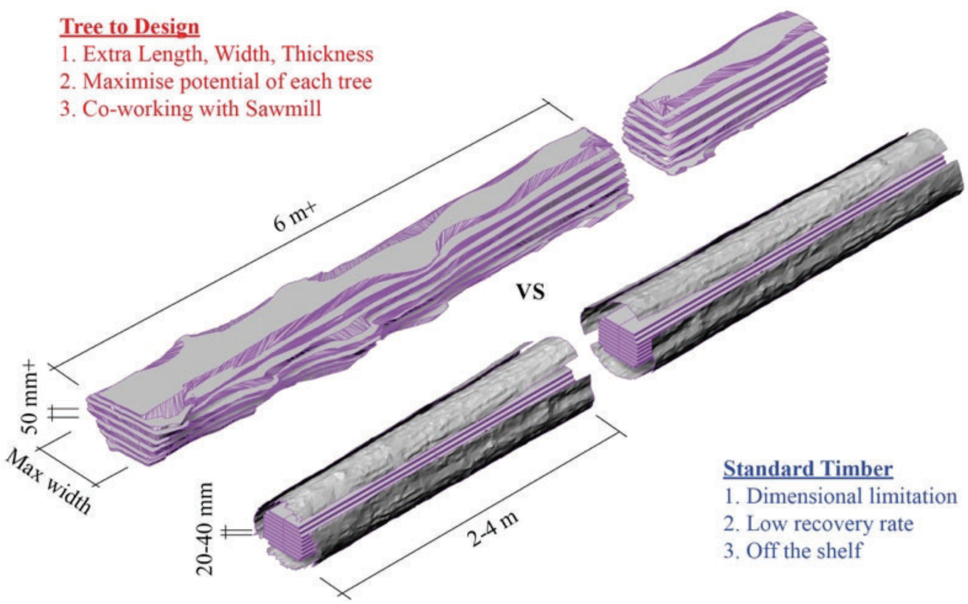

Figure 4. Standard timber dimension is difined by most efficient producation length and transporation, where as Tree-to-Design approch arrows maximum length and width as well as live edges of timber which are not readily availble in the commercial market.

Embrace Unique Live Edges
Incorporate the distinctive shapes of each live edge into the design, celebrating the natural beauty and variability of the upcycled timber. By adopting the *Tree-to-Design* approach, we were able to create biophilic design features that not only preserved the natural aesthetics of the upcycled trees but also highlighted their unique characteristics. This method allowed us to overcome the unpredictability of the timber supply and produce designs that were both sustainable and visually compelling.

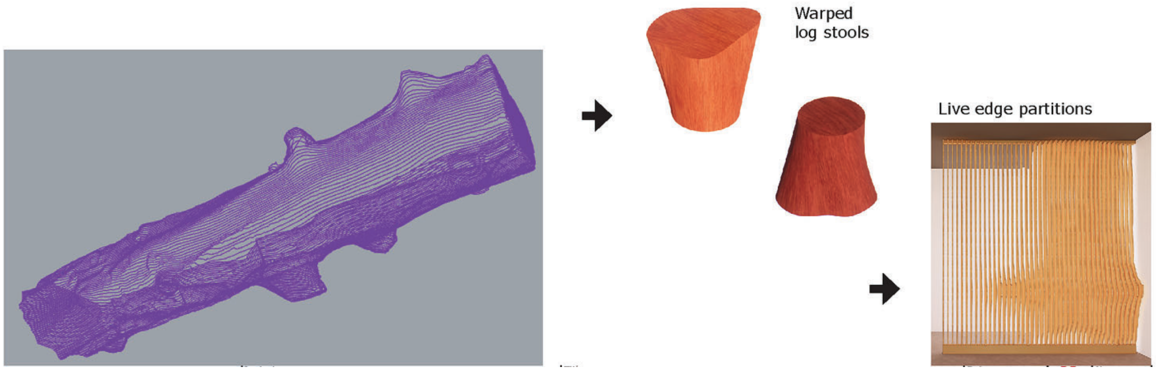

Figure 5. Left: 3D scanned log and 20mm pitch slices to simulate live edges. Middle: Cross sectional straight cut to create warped log stools. Right: longitudinal straight cut logs to create a series of live edge partitions.

2.5 ALLOCATING LOGS TO DESIGN

Seventeen trees designated for upcycling were categorized as follows:

Figure 6. Examples of log types. Far left: Straight; Left: Tapered; Right: Branched; Far right: Curved.

Straight Logs
Straight logs exhibit minimal curvature and maintain a consistent diameter along their length, making them the easiest to process. They provide the highest yield of uniformly shaped timber. However, very few, if any, straight logs were obtained during the upcycling process. Ideally, these logs were allocated to the *Rainbow Forum* and *Well Sphere*.

Tapered Logs
Tapered logs gradually decrease in diameter from one end to the other. Due to their shape, they yield less usable timber than straight logs and are less suitable for designs requiring uniform lumber. These logs were primarily designated for the *Rainbow Forum, Well Sphere,* and *Rainforest Collection*, where uniform lengths were required.

Branched Logs
Unlike single-stemmed trees, multi-branched trees develop multiple primary branches from a central trunk, resulting in distinctive branched logs. These logs were abundant in the upcycling process. Species such as rain tree and sea almond, known for their pronounced branching structures, were incorporated into the *Spring Square*, where their natural live edges could be fully appreciated.

Curved Logs
Curved logs exhibit natural bends and irregular shapes, posing challenges in processing due to their lack of straight edges. This results in a significantly lower recovery rate; however, they can still be utilized for producing smaller timber components, such as benches and table legs in the *Rainforest Collection*.

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Table 1. Initial Tree-to-Design Allocation Table

Species	Tags	Shape	No. of Logs	Tree-to-Design	Thickness	Width x Length
Jambu (*Syzygium grande*)	T0459-6	Curved + Multi Branched + Warped	2	Spring Square	20MM	150-500x 3500MM
	T0524-1	Curved + Multi Branched + Warped				
	T0524-2	Multi Branched + Straight				
	T0459-4	Warped	1	Rainbow Forum	100MM	200x3000MM
	T0459-7	Warped			Allocated as spare due to length shortage	
	T0459-8	Warped				
Rain Tree (*Samanea saman*)	T0439	Curved + Warped	9	Well Sphere	100MM	250x3000MM
	T0444	Tapered				
	T0445-6	Curved				
	T0442	Tapered				
	T0441-3	Tapered				
	T0441-6	Tapered				
	T0438-2	Curved				
	T0440-1	Tapered				
	T0440-2	Curved				
	T0440-3	Multi Branched + Straight				
	T0441-5	Curved				
	T0455-4	Curved				
	T0455-5	Curved				
	T0441-1	Tapered	2	Rainbow Forum	100MM	600x3000M
						400x3000MM
						200x3000MM
	T0455-3	Tapered			100MM	200x3000MM
	T0445	Warped	2	Rainforest Collection : Live Edge Tables	Allocated as spare due to length shortage	
	T0455-2	Curved + Multi Branched + Warped				
	T0455-7	Multi Branched + Straight				
	T0441-4	Tapered				
	T0441-2	Tapered				
	T0443	Curved + Warped	1		50MM	450x2400MM
	T0455-1	Curved + Warped	1			450x2400MM
	T0438-1	Curved + Warped	1			450x700MM
	T0434			Unused		
Rambutan (*Nephelium lappaceum*)	T0523-1	Curved + Multi Branched + Warped	1	Rainbow Forum	100MM	200x3000MM
	T0523-2	Curved + Multi Branched + Warped				
Sea Almond (*Terminalia catappa*)	T0942-2	Warped	1	Spring Square	20MM	150-500x3500MM
	T0942-1	Warped	2	Rainbow Forum	20MM	600MM
	T0971-1	Warped			Allocated as spare	
	T0971-4	Tapered				
	T0971-2	Tapered	1	Rainforest Collection : Benches	50MM	200x1000MM
	T0971-3	Tapered			50MM	200x400MM
Rosy Trumpet (*Tabebuia rosea*)	T1019-2	Tapered	2	Rainbow Forum	100MM	400x3000MM
		Tapered				200x3000MM
	T1019-1	Tapered				400x3000MM
	T1011-1	Warped		Rainforest Collection : Live Edge Tables	Spare	

The table illustrates the intended transitions from harvested trees to implemented designs. By analyzing each tree's shape, texture, length, and girth, we identified potential design applications. However, actual implementations deviated from this initial plan due to hidden internal defects in the logs, as well as warping and cracking that occurred during the drying process. Note: Tree tags are formatted as Tree Tag - Log Number (e.g., T0523-1).

During the design process, we faced significant challenges in accurately measuring logs and adapting to the limitations of the local sawmill's capabilities. Upon arrival, the felled trees were stacked for storage and processing, making precise measurement difficult, as individually laying out each log was impractical due to space and manpower constraints.

Additionally, the *Tree-to-Design* approach prioritizes wide and long logs, where timber girth and length influence the final design. However, the local sawmill's machinery had limited capacity to process logs beyond a certain length. To address this constraint, we standardized a maximum working length of 3 meters. The drying kiln further restricted processing, as logs thicker than 50 mm were difficult to dry within the available timeframe. Despite these limitations, we successfully achieved target thicknesses of 20 mm, 50 mm, and 100 mm while maintaining a maximum length of 3 meters.

Processing local hardwoods proved particularly challenging due to substantial variations in shape, size, and girth, requiring adaptive cutting strategies to maximize yield. These factors introduced an element of unpredictability in material recovery, necessitating a flexible approach to resource utilization.

2.6 BIOPHILIC DESIGNS: 1/F FLUCTUATIONS

Biophilic design enhances patient recovery in healthcare environments by leveraging the psychological and physiological benefits of biophilia [10]

1/f fluctuations are prevalent in nature and have been observed in various biological systems. These fluctuations appear to play a crucial role in sustaining life, as biological parameters continuously fluctuate over time. This variability is essential, as a complete absence of fluctuation would indicate the cessation of life. In this context, biological rhythm fluctuations are often regarded as indicators of vitality.[15]

The presence of *1/f* fluctuations at the organ level was first reported in 1982, when studies found that interval fluctuations in electrocardiograms (ECG) exhibited a *1/f* spectrum within a specific frequency range. Additionally, 24-hour heart rate variability (HRV) revealed significant differences in the mean HRV spectral exponent between young and elderly subjects. In stark contrast, a total artificial heart, when operating under fixed drive conditions, exhibits no fluctuation in pulse rate. [15]

Figure 7. Variations in the colors and textures of upcycled tropical timber exhibit 1/f fluctuation—an essential rhythm found in natural phenomena such as wind, waves, and natural light.
This balance between regularity and irregularity, as well as predictability and unpredictability, contributes to human comfort.

3 – DESIGN - UPCYCLING PROCESS

3.1 OPPORTUNITIES

Felled trees from urban and roadside environments often yield exceptionally long, thick, and wide timber planks. These dimensions are highly desirable in construction and furniture-making, offering unique possibilities for large-scale structural elements that are typically difficult to source from commercial plantations.

In Singapore, these felled trees represent an underutilized natural resource. Upcycling them provides a cost-effective alternative to imported timber, contributing to local sustainability efforts and reducing dependence on external supply chains. This untapped potential supports a wide range of applications, from structural components to biophilic design, fostering the use of local materials and promoting a circular economy.

3.2 CHALLENGES

The client seeks to preserve the legacy of Alexandra Hospital's green campus and rich history through upcycled timber installations. However, a key challenge lies in sourcing all timber exclusively from the construction site, limiting the availability of suitable material. The recovery rate is estimated to be below 50% due to defects such as larvae infestations, cracks, and internal decay. This necessitates a flexible design methodology that can accommodate the unpredictable nature of the upcycling process, ensuring adaptability to variations in timber quality and quantity.

The inherent unpredictability of upcycled timber characteristics prevents full visualization of design outcomes in advance. As a result, client support for the *Tree-to-Design* approach is essential. This methodology prioritizes adaptability, allowing the design process to evolve based on the unique properties of each timber piece.

While the timber itself is available at no cost, processing it—particularly extra-large planks—incurs significant expenses and logistical challenges. Drying, cutting, and storing these irregularly sized pieces require specialized equipment and facilities, adding to the overall complexity of the upcycling process.

The *Tree-to-Design* approach maximizes the aesthetic and functional potential of upcycled trees as biophilic design elements. Key features include**:**
1. Sequential live edges partitions (*Spring Square*),
2. CNC-carved biomorphic columns (*Well Sphere*),
and 3. Mass-customized modular feature walls (*Rainbow Forum*) representing the diversity of the upcycled timber species.

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3.3 *BIOHEAL* DESIGN ELEMENTS

Spring Square (Sequential Live-Edges Partitions): Spring Square features a distinctive partition wall that arranges natural live edges of timber in a direct sequential order, preserving the original log structure from which they were harvested. This design highlights the biophilic aesthetics of the timber, achieving a balance between regularity and irregularity, as well as predictability and unpredictability.

Figure 8. Left: Spring Square – Sequential live edges representing the balance between regularity and irregularity, predictability and unpredictability. Right: 20 mm sliced Jambu tree. (Image courtesy of Tat Hin Timber)

Well Sphere (CNC-Carved Biomorphic Columns): Gracefully sculpted using Computer Numerical Control (CNC), the timber columns transition from a straight base to a concave upper cornice, evoking the form of a new tree. This design symbolizes renewal and echoes the resilience of nature..

Figure 9. Left: Well Sphere – Transition from a straight base to a concave cornice, representing renewal and the resilience of nature. Right: Finishing of a 100 mm thick CNC-milled rain tree plank for Well Sphere columns. (Image courtesy of Tat Hin Timber)

Rainbow Forum (Mass-Customized Modular Feature Walls): The *Tree-to-Design* approach was employed to maximize the potential of each harvested tree, embracing the natural diversity of widths, colours, and textures. This method highlights biodiversity while reflecting the vibrancy of Singapore's community. A series of extra-large timber blocks were hand-engraved into concave profiles, forming a 'timber tapestry' that symbolizes collective hope and renewal.

Figure 10. Rainbow Forum – A series of extra-large timber blocks hand-engraved into concave profiles using the Tree-to-Design approach, maximizing the potential of each harvested tree.
The design embraces biodiversity in the tropics through the natural variation of widths, colors, and textures.

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4 – OUTCOMES AND REFLECTIONS

As a trial-and-error pilot project, all stakeholders—including the client, architect, and contractors—faced and navigated unforeseen challenges associated with upcycling felled trees from the construction site. *"The collaboration between SkyTimber™ and NUS with our Office of Campus Planning resulted in a beautiful tapestry and façade using upcycled materials, adding a nostalgic touch of terracotta exterior,"* said Dr. Jason Phua, CEO of Alexandra Hospital. *"The aesthetically pleasing design identity and functional furniture for our staff and patients demonstrate our appreciation and respect for nature."* [16]

The key outcomes and reflections are summarized as follows:

Spring Square (Sequential Live-Edges Partitions): Achieving continuous patterns in live edges proved challenging due to inevitable discontinuities between different logs. Additionally, since live edges are the peripheral portions of juvenile sapwood, they were prone to blue staining, which impacted the overall aesthetics. Despite these challenges, the biophilic quality of 1/f fluctuation was successfully represented, creating a dynamic contrast with the surrounding interior.

Well Sphere (CNC-Carved Biomorphic Columns): The CNC carving process, which transitioned from a concave base to a straight cornice, was executed with high precision, demonstrating smooth and gradual geometric transformations. This design effectively symbolized nature's renewal, reinforcing the therapeutic ambiance of the rehabilitation room through intricate biomorphic columns..

Rainbow Forum (Mass-Customized Modular Feature Walls): The modular and interchangeable components allowed for flexibility in on-site installation. This adaptability was particularly beneficial in accommodating the natural variations of the upcycled timber, such as unexpected knots, cracks, and textural differences among planks.

Additionally, while the felled trees were cost-free as materials, the costs associated with processing and storage were underestimated. The one-year gap between tree felling and the *BioHeal* installation underscored the critical need for secure log storage, highlighting the importance of planning for long-term material management in future projects.

Overall, this pilot project provided valuable insights into the practicalities and challenges of integrating upcycled felled trees into construction. The knowledge gained will inform more efficient and effective practices in future projects, furthering sustainability and the innovative use of natural resources.

5 – CONCLUSIONS AND RECOMMENDATIONS

Felled tree upcycling presents a promising strategy for supporting an aging population and reducing carbon emissions, particularly in resource-scarce Singapore. However, scaling this practice in commercial construction requires a robust social infrastructure and appropriate cost estimation frameworks. While felled trees from roadside and construction site clearances have been informally repurposed for applications like street furniture, they have yet to be formally integrated into the construction industry.

The *Tree-to-Design* approach, as implemented in the *BioHeal* project, represents a pioneering effort made possible by strong client support. This initiative has positively influenced public perception, demonstrating that even in resource-scarce Singapore, locally sourced renewable materials can be effectively utilized. However, to facilitate large-scale adoption of felled tree upcycling, a structured framework is essential.

A key challenge is the irregular supply of various tree species, sizes, and properties, given Singapore's diverse urban landscape. To address this, we recommend establishing a public stockyard—a centralized facility for storing felled trees. This would provide a mechanism for architects, designers, and developers to access, evaluate, and select suitable materials, thereby integrating upcycled timber into mainstream construction. Such an initiative would not only support sustainability efforts but also ensure greater resource efficiency and material accessibility within the industry.

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https://doi.org/10.52202/080513-0618

REFERENCES

[1] L. T. Seng, "The Greening of Singapore: Parks and Roadside Trees from Colonial Rule to the Present," *Journal of the Malaysian Branch of the Royal Asiatic Society,* vol. 91, no. 2 pp. 79-101, 2018, doi: https://doi.org/10.1353/ras.2018.0031.

[2] P. Y. Tan, et al., *Carbon storage and sequestration by urban trees in Singapore*. Singapore: Centre for Urban Greenery and Ecology, 2009.

[3] M. S. C. Lab. "Treepedia." https://senseable.mit.edu/treepedia (accessed 2024).

[4] N. P. Board. "One Million Trees Movement." https://www.nea.gov.sg/docs/default-source/default-document-library/annex-e---factsheet-on-one-million-trees-movement.pdf (accessed 22nd Jun. 2024).

[5] C. Yong, "Three brothers give local felled trees a new lease of life in furniture and fine objects," in *The Straits Times*, ed, 2022.

[6] "Oral Answer By Ministry Of National Development On Tree Cutting And Replanting In Residential Areas." Ministry of National Development, Singapore. https://www.mnd.gov.sg/newsroom/parliament-matters/q-as/view/oral-answer-by-ministry-of-national-development-on-tree-cutting-and-replanting-in-residential-estates (accessed 30th Nov. 2022).

[7] A. Amirul Hafit, "Biophilic Rejuvenation - Upcycling Singapore's Roadside Trees," Master of Architecture, Department of Architecture, National University of Singapore, 2022.

[8] S. F. Chin, "S'pore's population ageing rapidly: Nearly 1 in 5 citizens is 65 years and older," in *The Straits Times*, ed. Singapore.

[9] S. Khalik, "Bed crunch at Singapore hospitals: Some patients are stuck in emergency departments," in *The Straits Times*, ed. Singapore.

[10] W. Browning, et al., *14 Patterns of Biophilic Design - Improving Health & Well-being in the Built Environment*: Terrapin Bright Green LLC, 2014. [Online]. Available: https://www.terrapinbrightgreen.com/reports/14-patterns/.

[11] C. e. a. Lingxiu, *Alexandra Hospital: A Legacy of Care*. Singapore: Asiapac Books Pte Ltd, 2024.

[12] "Alexandra Hospital, My Queenstown Heritage Trail." National Heritage Board, Singapore. https://www.roots.gov.sg/places/places-landing/Places/landmarks/my-queenstown-heritage-trail/alexandra-hospital (accessed 24th Jun. 2024).

[13] D. Tan. (2023) Tree Upcycling at Alexandra Hospital. *Nature Watch*. p.14-17.

[14] T. Enters, *ASIA-PACIFIC FORESTRY COMMISSION, Trash or treasure? Logging and mill residues in Asia and the Pacific*. 2001.

[15] T. Musha and M. Yamamoto, "1/f fluctuations in biological systems: Magnificient Milestones and Emerging Opportunities in Medical Engineering," New York, 1997, vol. 19, no. Conference Proceedings: IEEE, pp. 2692-2697.

[16] "BioHeal: Tree upcycling for architectural healing." College pof Design and Engineering, National University of Singapore. https://cde.nus.edu.sg/news-detail/bioheal-tree-upcycling-for-architectural-healing/ (accessed 23rd Jun. 2024).