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Trained as an Industrial Designer and an Architect, Himanshu Yogi received his Master's degree in Industrial Design and Bachelors in Architecture from the School of Planning & Architecture, Delhi in 2019.

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His design experience of more than two decades spans fields of Product, System and Communication Design. As a keen academician with interests ranging from System to Social Design, he is also visiting faculty at various institutions like IIT Delhi and RMIT Melbourne as design mentor.

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Possibilities of Architectural Modelling with Lac

Theme: Encouraging usage of natural resins like lac in prototyping

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Abstract: Plastics are widely used in architectural modelling, be it acrylic sheets stacked together to form block models or a 3D printed sectional model made out of plastic filaments. Although with the raising concerns about plastic waste, the focus is shifting on encouraging bio-degradable plastics. In these circumstances, Natural resins have emerged as a substitute to conventional plastics. The knowledge of natural plastics or resins is known since ages and one of these natural resins is Lac. In India, Lac is a general term for the products of resinous secretions from Lac beetle. Lac as a material has low embodied energy and can also be reused in manufacturing applications for its thermoplastic properties.

The study is intended to investigate the types of architectural modelling & model making materials and further exploring possibilities of using lac in modelling. The sustainability of the material is assessed by analysing its physical and chemical attributes. Further, hands-on methods and experiments were applied to Lac to check its suitability for architectural modelling. The study reveals that casting, injection moulding, and 3D printing are feasible with lac. Other applications in architectural modelling using lac as a material can be further investigated.

KEYWORDS: ***Lac, Natural Resin, Modelling, Manufacturing, Sustainability***

Introduction

In design practice, process of design has given more emphasis than the end result. This entire process involves stages of understanding the context, ideation of concepts, prototyping and design development. As a designer, focus is given for a sustainable design for the benefit of the community and the environment. Whereas the prototyping stage that involves modelling of various stages, generates lots of non-recyclable waste. Hence, tagging this prototyping process as unsustainable.

Currently, model making has been classified in two ways, namely, Subtractive and Additive modelling. Subtractive modelling involves sculpting out material to get the desired form whereas additive modelling is done by adding different layers on each other to produce the form. Although the subtractive modelling creates more waste but the materials used in both ways aren't reusable to make new models.

Lac is a natural resin whose jewellery products of Jaipur, Hyderabad and Patna are very popular handicraft. The bangle makers melt the lac and mix it with stone dust and prepare a sticky paste to produce bangle sticks. These sticks are folded around a wooden cylindrical mould to give the shape of a bangle. The process of melting and making lac bangles is similar to clay modelling added with heating. The thermoplastic properties of lac enable it to be reused again by heating it. This allows bangle makers to make corrections if something goes wrong. Also, lac being a food-grade material doesn't release any harmful fumes. Hence lac has a promising prospect, of being used as an eco-friendly alternative material for modelling & prototyping.

Figure 1:Red marked "Maniharon ka Rasta" street for lac bangles in walled city, Jaipur, and artisans working with lac. (Left to right)

Architectural Modelling

It is an essential tool that helps an architect from design's conception to the completion stage. A 3D model is a must to understand the design in wholesome way and a physical model is the best way to convey design concepts.

In the case of architecture where one can see the product only after its completion, model making bears extreme relevance. These models not just help in visualization but they are also required during design development stages. Through these models an architect gets to understand, analyse, revisit and further refine their design.

Modelling helps in better understanding of the composition of form, proportions, materials, colours and textures. They provide an opportunity to develop and explore the relationship between the open & built spaces and unlocks the prospect to play with colours, textures and materials.

Figure 2: Design discussion through model (Urban Design Studio, SPA Delhi 2014)

Architectural Modelling: Earlier

Before the advent of 3D development and rendering softwares, physical models were the only medium for architects to represent their creative ideas in three dimensions. The art of modelling has also evolved with the arrival of new materials and manufacturing techniques. Earlier models were handcrafted out of wood, stone, clay and plaster. As these models were meant for presentation before kings and nobles, it was frequently tried to mimic the actual structure by using similar colours and textures.

Architectural Modelling: Nowadays

In the digital age where one can visualize designs with the help of 3D software, physical models haven't lost their relevance. It's the very tangible aspect of physical models that provide the opportunity of exploration in a more rigorous manner in comparison to its digital counterparts.

Nowadays, a variety of materials and manufacturing techniques are used to make a model, while considering the availability of budget & time. Casting, hot wire cutting, laser cutting and 3D printing are few techniques that are currently used with the materials like paper, wood, plastics, resins and many more.

Planning for Modelling

Determining the scale and detailing required, are the first step in deciding the material and techniques to be used in modelling. Once the material is selected, a strategy is formed that requires less time duration, minimum cost and ease of modelling. Time, cost and labour are the major parameters in determining a manufacturing technique for making a nice and informative architectural model. Even while selecting a material, it isn't necessary to stick with just one type of material. Often designers use a combination of two-three materials, best suited to the composition and objective of modelling.

Objective of Modelling

A three-dimensional model serves a variety of purpose. It could be a conceptual model made during development stages or a presentation model created to explain the design. Depending upon the architect's objective to communicate their design, models can be classified into following categories.

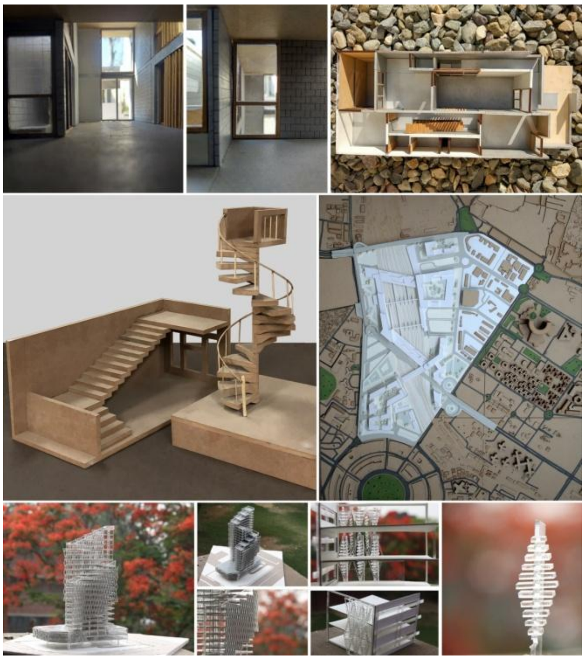

Figure 3:Different types of models. Interior model (Top three), Sectional & Zoom-in model (Middle left), Site Model (Middle right), Structural & façade Model (Bottom six)

Block Models

A Block Model represents the massing, scale and proportion of a design. Instead of providing the detailed information, these types of models give a simplified idea of various components of a design. It is an efficient tool to take any on-spot design decisions and refine a raw concept. Such models are easier to make and enables a designer to explore a variety of concepts without worrying about details related to material, construction and structure.

One more benefit of Block Models is that a variety of materials can be used to make them. As the primary objective of this type of modelling is to study the form of design, so there's no requirement to mimic the final design's materials. This type of prototyping is used to examine how different components of a design are functioning together and along with its immediate context.

Site Models

"How we approach a building?" is an important aspect of Design. Site Models comes handy in understanding the circulation around the site and design's relation with the context. After conceiving the form, Site Model is the next step in design detailing considering the immediate surroundings of the structure. Site model is used to study the effects of new structure in the existing urban sprawl.

As the objective of Site Models is to study the relation between new design and the context, the scale of the design reduces to a simplified block model, purely representing the design without any unnecessary details. Omitting these details lets the designers

to focus on the design without getting involved in rigours detailing. Depending upon the scale and size, contrasting materials or colours are used to highlight the new design in its surrounding context. These types of models help the designers in understanding the movement patterns, topography, natural and man-made features around the site on urban level. Therefore, it is widely used in explaining urban design, landscape design, transport-hub design, campus design and mass housings.

Zoom-in/Part Models

They are all about detailing and explaining the intricacies of a design. As per the scale of a given design proposal, zoom-in models are used for both detail development and understanding the working of any detail. These models also help in on-site execution of these details. The need to examine a detail, leads to these models being built on a scale of 1:20, 1:10, 1:5 or in case of working prototypes it could be as big as 1:1 scale. As the scale of the design increase, focus shift on using or presenting the actual materials, colours & textures. Therefore, it is widely used in explaining interior & exterior design, furniture design, product design, joinery or fixing details or any other details required for execution on site.

Structural Models

They are characterised by their skeletal appearance and help in understanding the assembly of a framework and explaining the structural system of a design. Throughout the design development process, structural models aid in backing the raw concepts and ideas by providing the structural validation to them. As compared to their digital counterparts, the physical models help in pinpointing the issues, which may not appear in CAD models. For architects, these models are really useful in comprehending how

various elements of structural design are supporting and fitting together and innovating these elements as per their design concepts.

Sectional Models

Emphasising on sections while design development process has a direct impact on the spatial quality of a design. Sectional models are a great tool to understand a design that involves built spaces on different levels. Depending upon the scale and size, sectional models are a perfect tool to understand the spatial relationship around or within the built spaces. At the same time, it also demonstrates the structural framework of a built-up cut through that section line. Section models sizes can vary from zoom-in model to site models providing the insights to a designer that eventually help in three-dimensional modelling.

Material Selection

This plays a pivotal role in architectural modelling. It provides the opportunity to explore and materialize the concepts into final design. Through modelling, selection of material colour palette becomes easier by trying different compositions on it. After finalizing the material, the next step is to decide a suitable manufacturing technique. Here are the most commonly used model making materials and the techniques, analysed on the parameters of Time, Cost & Labour and End-of-Life of these models.

Paper & Cardboard

Technique applied	Time, Cost & Labour	End-of-Life
Hand cutting	More time & labour but less cost	• Models once made can't be reused but paper can be recycled. • Although paper is an organic material so it will degrade without polluting the ground.
Laser cutting	Less time & labour but more cost	
Pasting or Assembly	Done manually	
Colour & finish	Available in different colours and textures and printing is also feasible.	

Wood/MDF/HDF

Technique applied	Time, Cost & Labour	End-of-Life
Hand cutting	More time & labour but less cost	• Models once made can't be reused again and but wood can be recycled. • Wood is an organic material so it will degrade without polluting the ground.
Laser cutting	Less time & labour but more cost	
Sanding	More time & labour but less cost	
Pasting or Assembly	Done manually	
Colour & finish	Available in different shades of brown and have variety of grains and etching via laser cutting is possible.	

Natural clay or plasticine

Technique applied	Time, Cost & Labour	End-of-Life
Hand modelling & sculpting	More time but easier to make and one time cost for sculpting tools	• Models once made from natural clay can't be reused

Wire/thread cutting	**Easier to cut straight edges, nothing significant in terms of time & cost**	**again and it usually ends up in dump yard.** • **If not baked, plasticine models can be reused again.**
Casting	**Involves extra time, cost & labour for development of moulds. Once done models need time to get dry**	
Colour & finish	**Available in different shades of brown, whereas plasticine has variety of colours and both of them have smooth matte finish.**	

Plaster of Paris (POP)

Technique applied	**Time, Cost & Labour**	**End-of-Life**
Hand modelling & sculpting	**More time but easier to make and one time cost for sculpting tools**	• **Models once made can't be reused again and it usually ends up in dump yard.**
Wire/thread cutting	**When wet it's easier to cut straight edges, nothing significant in terms of time & cost.**	
Casting	**Involves extra time, cost & labour for development of moulds. Once done models need time to get dry. Good for multiple repetitive models.**	
Colour & finish	**Has a light grey colour but we can try and mix different colours in it and it has a smooth matte finish.**	

Acrylic Sheet

Technique applied	**Time, Cost & Labour**	**End-of-Life**
Laser cutting	**Less time & labour but more cost**	• **Models once made can't be reused again and it usually ends up in dump yard.**
Pasting or	**Done manually**	

Assembly		• Acrylic is a type 7 non-biodegradable plastic. • Can be recycled but segregation is difficult.
Colour & finish	A variety of colours & transparency and available in both glossy & matte finishes.	

Polystyrene

Technique applied	Time, Cost & Labour	End-of-Life
Hand modelling & sculpting	More time but easier to make and one time cost for sculpting tools	• Models once made can't be reused again and it usually ends up in dump yard. • Polystyrene is a type 6 plastic and it isn't a bio-degradable plastic. • Recycling of Polystyrene isn't feasible, as it is cheaper to produce and hard to collect.
Wire/thread cutting	When wet it's easier to cut straight edges, nothing significant in terms of time & cost	
Pasting or Assembly	Done manually	
Colour & finish	Produced in 2-3 different shades such as blue, white, pink and yellow and it has a matt	

PLA, ABS & Nylon Filaments

Technique applied	Time, Cost & Labour	End-of-Life
FDM 3D printing	More time, easier to make and expensive method	• Models once made can't be reused again. • The most commonly used materials in FDM 3D printing are PLA, ABS & NYLON • PLA is a bio-plastic, hence, it degrades easily in
Pasting or Assembly	Done manually	
Colour & finish	Filaments can have a variety of colours and the model bears a	

	layered texture of additive printing.	**controlled environment.** • **All of these materials are thermoplastics hence, they are recyclable.**

Material Analysis

- ***The cost of model making is inversely proportional to time and labour. As the cost increases, time and labour decreases.***
- ***Except plasticine, none of the materials can be reused to make new models.***
- ***Being an organic material paper, wood and natural clay don't have any adverse effect on the soil and it gradually degrades.***
- ***Whereas acrylic sheets, polystyrene and 3D printed models of ABS & Nylon aren't bio-degradable and remain intact for decades.***
- ***Thermoplastic properties of PLA, ABS and Nylon enable them to be recycled again but it requires more than 150°C for melting.***
- ***The fumes generated while laser cutting of plastics and organic materials such as paper and wood is unpleasant and toxic. A prolonged exposure to these fumes has harmful effects on human health.***[1]
- ***The Fused Deposition Modelling (FDM) type of 3D Printing involves melting of filaments at temperature more than 150 °C, which generates harmful fumes.***[2]

[1](R. J. Roach 1998), R. J. Roach, E. A. Raymond, J. R. Tyrer, and B. L. Sharp. 1998. "The indexed assessment of fumes generated by high power laser material processing." Journal of Laser Applications Volume 10, Issue 3 (1998).
[2](Singh 2017), Singh, Neelam Bharti and Shailendra. 2017. "Three-Dimensional (3D) Printers in Libraries: Perspective and Preliminary Safety Analysis." Journal of Chemical Education 2017 94 (7) 879-885.

Understanding Lac

In India, Lac is a general term for products of resinous secretions from Laccifer Lacca beetle, both before and after various stages of its refinement. Refined lac is also known as Shellac and raw lac as Stick Lac.

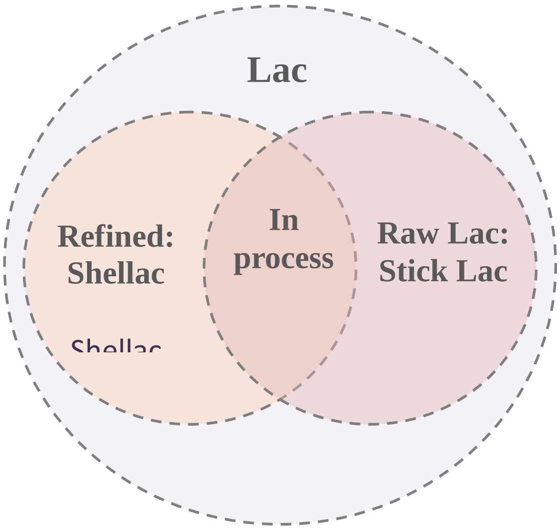

Figure 4: Lac as a general term

Lac is known to Indians from since decades. Its usage as sealing an envelope and as a stamp is still common in various parts of the subcontinent. A brief account about the medicinal and cosmetic qualities of lac has been mentioned in ayurvedic books of Atharva-Veda, Charak & Sushrut Samhita.[3] These common reference shows a familiarity with resin and its uses within the community.

Nomenclature

The word *Lac* is itself derived from the Sanskrit word, *laksha*, which means 100,000 units. It is a common belief that the word refers large number of insects it takes to make a unit of finished lac.

[3](Pt. Kasinath sastri 2017), Pt. Kasinath sastri, Dr. Gorakh Nath Chaturvedi. 2017. Caraka Samhita. Kshatkshin Chikatsa Chapter 11. Varanasi: Chaukhambha Bharati Academy.

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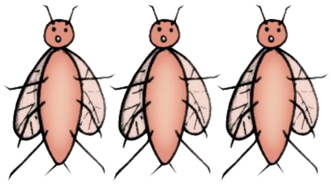

Figure 5: Insects dies to produce 1 Kg of lac(approx.)

Lac's Production

Lac is secreted by Laccifer Lacca beetle, to protect itself from other predators. The beetle latches onto the branches of selected host trees, thereafter sucking sap and secreting a resinous material known as lac.

This insect can be found in warmer climates, propagation and harvesting for economic gains, mainly in the forested areas of India, Thailand, and China. On an average, India produces about 21,000 metric tonnes of lac annually, and contributes around 55% of the total world demand. Over 90% of India's lac produce comes from the states of Chhattisgarh, Jharkhand, Madhya Pradesh and West Bengal.[4]

Thus, by encouraging the usage of lac can immensely benefit around one lakh farmers of these states by generating livelihood options for them.

Lac's Properties

Chemical Properties of Lac

[4](PRADAN n.d.), PRADAN, Professional Assistance For Development Action. n.d. "Lacquered Dreams, Promoting livelihoods through Lac." www.pradan.net. Accessed January 2019. http://www.pradan.net/.

Lac is mainly composed of 90% resin, which is further divided into two parts: 25% soft (ether-soluble) resin, and 75% hard (ether-insoluble) resin. According to John Mills and Stuart White, shellac is a terpenoid resin consisting of low molecular weight polymers (oligomers) formed by esterification of polyhydroxy carboxylic acids with one another.[5]

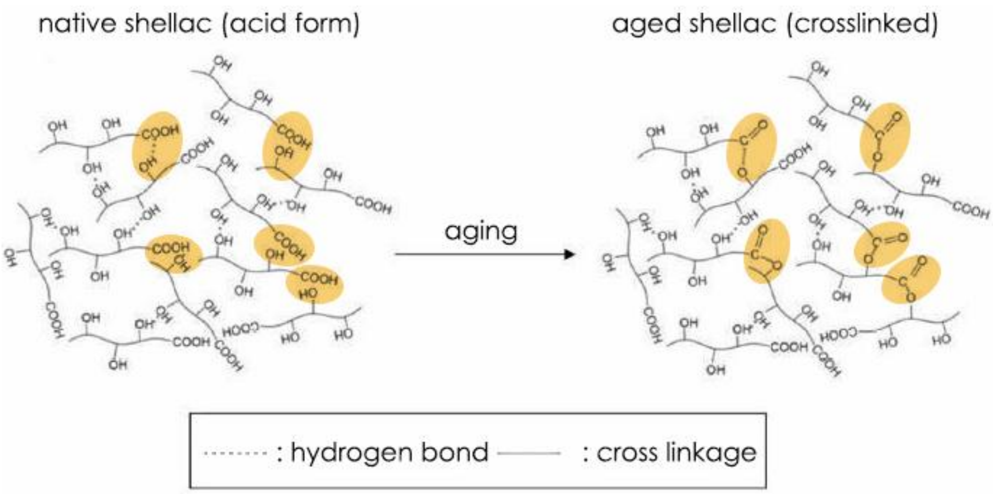

Figure 6: The schematic description of the process of esterification, which takes place during aging of shellac.6

Lac resin was a viscous, colourless liquid when first exuded by Laccifer Lacca, becoming harder and darker as esterification takes place. The polymerization of shellac takes place by esterification and the expelling of water (H2O), resulting in blocking and reduced solubility. Figure 4 shows the reaction of self-esterification that happens in shellac as it ages.[7]

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[5] ***(Derry 2012, 81), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo***

[6] ***(Derry 2012, 85), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo***

[7] ***(Derry 2012, 85), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo 8 (Derry 2012, 85), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis,***

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As a result of esterification, shellac deteriorates with gradual loss of alcohol solubility, increase in melting point, and rise in alcohol insolubility, decreasing life and fluidity testing, as well as darkening in colour.[8]

Physical Composition of Refined Lac

Shellac's physical components

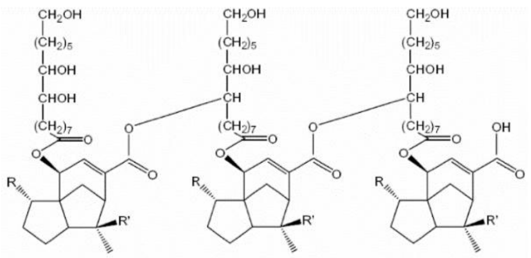
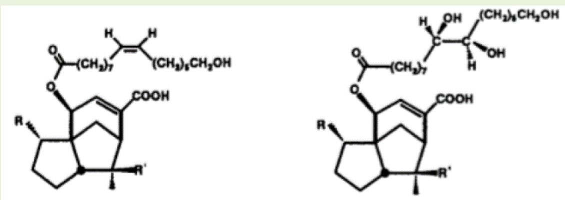
Resin (90.5%)	**Dyestuff (0.5%)**	**Volatiles (1.8%)**
Hard Resin (75%) 	**The composition of Lac seems to vary according to host tree, two acid groups have been identified in shellac; one being aleuritic and butolic acids, and the other being jalaric acid**	**Majorly H2O**
Soft Resin (25%) 		**Wax**

Table 1: Shellac's physical composition.9

Physical Properties Lac

Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo
[8](Derry 2012), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo
[9](Derry 2012), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of **Humanities, The Institute of Archeology, Conservation and History, University of Oslo**

- **Transparency: Depending on its wax content, lac has varying degrees of transparency. As the lac resin mixture is an amorphous polymer, a dewaxed variety will have higher transparency, since the wax particles naturally present in lac interfere with the passage of light.**
- **Gloss: The ability of a surface to reflect light and produce mirror like reflection is known as gloss finish. It is measured by the specular reflection of that surface. A matte surface displays the lower value of specular reflection, while a glossy surface has a higher value. Traditionally, lac has been used to achieve glossy finish but by applying methods like sanding and buffing, it can produce matte finish too.**
- **Colour: The natural colour of lac span from a rich amber yellow, to a dark reddish-brown. It is available in a wide range of colours and can be dyed to produce almost any colour. Mixing with pigments produce more opaque qualities, as the pigment blocks and scatters the visible light.**
- **Hardness: Lac buttons available in market are quite brittle in nature but as lac was traditionally used as a coating for floors and bowling alleys, it is certainly durable enough as a finishing material.[10]**
- **Barrier Properties: Lac coating displays excellent barrier characteristics against moisture, oxygen, temperature and humidity; hence, it is used as an organic coating for fruits and chocolates. The IINRG has developed a lac-based fruit coating formulation for Kinnow to increase its self-life.[11]**

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[10](Derry 2012), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo

[11](ICAR Review Committee n.d.), ICAR Review Committee, IINRG, Ranchi. n.d. "Technologies Available." Accessed January 2019. https://iinrg.icar.gov.in/.

- **Flexibility and Adhesion in Lac: According to William Gardner, the soft resin part of shellac acts as a natural plasticizer, whereas the hard resin is a brittle substance. Cockeram et al. reported that hard resin component is brittle but its adherence properties exceed those of shellac as a mixture. A blend of flexibility and adhesion means that a shellac film stick to the surface while it is sufficiently flexible to allow for some movement without failing as a coating.[12]**

  The superior adhesive abilities of shellac are suitable as a sealer/barrier coating when other coatings are to be used as topcoats, or to overcome surface problems, such as silicon contamination.

Industrial Applications of Lac

Surface Coating Industries	• **Heat and waterproof French polish (for glossy and attractive finish on wooden furniture, radio, TV cabinets, musical instruments, etc.)**
	• **Picture varnish (to protect pictures and paintings against dust, abrasions and humidity)**
	• **Book varnish**
	• **Emulsions and oil paints, synthetic enamels and ink**
Adhesive Industries	• **Gasket shellac compound (for repair and maintenance of automobile engines)**
	• **Sealing wax**

[12](Derry 2012), Derry, Juliane. 2012. Investigating Shellac: Documenting the process, Defining the product. Project-Based Masters Thesis, Oslo: Faculty of Humanities, The Institute of Archeology, Conservation and History, University of Oslo

	• **Lac glue (for glass, metal, plastic wood and cloth)**
	• **Particle board (as partition wall or false ceiling)**
	• **Making of bangles**
Electrical Industries	• **Insulating varnish (in electric motors, transformers and for manufacturing of other laminated products)**
Food & Medicines	• **As a fruits coating to increase the shelf life. The small amount of wax content in lac prevents moisture loss during fruit's storage.[13]**
	• **As a protective candy coatings or glazes on candies like Reese'sPieces, because of its ability to provide a high gloss in relatively thin coatings. It is approved by the FDA as a food safe coating.[14]**
	• **For coating enteric pills, so that they do not dissolve in the stomach, but in thelower intestine, which alleviates upset stomachs. It's also used as a coating on pills to "time release"medication.[15]**
Miscellaneous Applications	• **By-products such as lac dye and lac wax**

[13](OMRI 2014), OMRI, Organic Materials Review Institute (NGO). 2014. "Orange Shellac: Handling/Processing." Technical Evaluation Report compiled by OMRI for the USDA National Organic Program.

[14](OMRI 2014), OMRI, Organic Materials Review Institute (NGO). 2014. "Orange Shellac: Handling/Processing." Technical Evaluation Report compiled by OMRI for the USDA National Organic Program.

[15](Daniele Giovannone 2015), Daniele Giovannone, and Carlo De Angelis. 2015. Composition comprising shellac and/or a salt there of and sodium starch glycolate. Europe Patent EP 2 598 122 B1. 16 Sep.

	• **Jewellery and ornaments from valuable-coloured stones**
	• **For polishing and sharpening stones**

Table 2: Applications of Lac.16

Testing Manufacturing Processes

Through literature research, the physical and chemical properties of lac were explored. To understand lac as a material and check its suitability for modelling, it was necessary to try-out some tests on lac.

Casting with Lac

Test-01

Lac buttons were heated inside a stainless-steel bowl through gas stove. It was observed that lac got melted and then, started burning because of direct heating and got stick to the container. Dense lac globules were produced which have lower density than water.

Figure 7: Burned lac and lac globules.

[16](PRADAN n.d.), PRADAN, Professional Assistance For Development Action. n.d. "Lacquered Dreams, Promoting livelihoods through Lac." www.pradan.net. Accessed January 2019. http://www.pradan.net/.

Test-02

Lac buttons were heated inside an earthenware using an electric heater. Lac got melted and then, started burning because of direct heating. The temperature was then decreased so no lac globules were formed. As the melted lac is spread all over the utensil, upon cooling the utensil gets coated with lac. The moment lac starts cooling down its fluidity decreases. The layer of lac sticks with the earthenware also.

Figure 8: Melted lac in earthenware.

Test-03

This test involves heating of lac buttons indirectly inside a stainless-steel utensil. A mould of POP was created and Vaseline and coconut oil was applied on the surface.

Figure 9: POP mould on left being prepared for casting.

The mould was divided into 4 parts: surface coated with coconut oil, water applied over POP surface, surface coated with Vaseline and POP surface left as it is. Lac was heated in a container filled with water so as to avoid burning. Molten lac is denser than water, hence, it settles down and then the excess water is removed. Molten lac was poured over POP mould and left for cooling. After cooling, the POP mould is scrapped out to get lac.

Figure 10: Casting with lac using POP mould.

While removing POP, the surface applied with coconut oil and Vaseline releases easily but oil acts as a better releasing agent. Due to the presence of a significant amount of water in molten lac, bubbles appeared on the final form. The translucency of casted lac still remains intact.

Figure 11: Casted lac form

Test-04

Figure 12: Mixing equal amount of lac and Berja gum by weight (top left), preparing silicon mould for casting (top right), Pouring molten lac in silicon mould (bottom left), taking out the artefact out of mould (bottom right)

This test was done to check whether molten lac sticks to silicon's surface or not and if it is possible to produce similar artefacts using the same mould. Equal proportion of lac and Berja gum were melted together in water. Excess water was removed by boiling again.

Figure 13: Lac artefact produced.

Silicon mould was prepared for casting. Molten lac was poured in it and cooled for 10-15 mins to obtain the artefact. First successful solid lac product manufactured by casting. Because of equal proportion of gum and lac, setting time of final product increased. Lac didn't stick to silicon's surface. Rough finish of artefact can be attribute to presence of water. Same silicon mould can be used to produce similar artefacts. Silicon mould was able to withstand the heat of molten lac.

Press Moulding with Lac

Test-05

This test involves melting lac with water. Excess water from lac was removed and then it was boiled again to remove the

remaining water. After this, colour was mixed with molten lac to prepare a wet glass surface.

Figure 14: Pouring and spreading molten lac.

It was observed that water bubbles didn't appear on lac sheet and a uniform finished surface was produced after mixing colour. It was opaque. Lac didn't stick to glass because of water. The sheet got easily broke when dropped from a height of 1.2 meters.

Test-06

This was performed to check the strength of lac sheet. A mixture having 60% lac (powdered form), 30% wood flour and 10% Berja gum powder was prepared and placed on a plate. The container with the plate was filled with water and the boiling water melted lac without burning it. The plate was coated using Vaseline as a releasing agent. Cotton cloth was used to press the mixture constantly for an hour and let the mixture cool afterwards.

Figure 15: Preparing the mixture of lac, gum and wood flour.

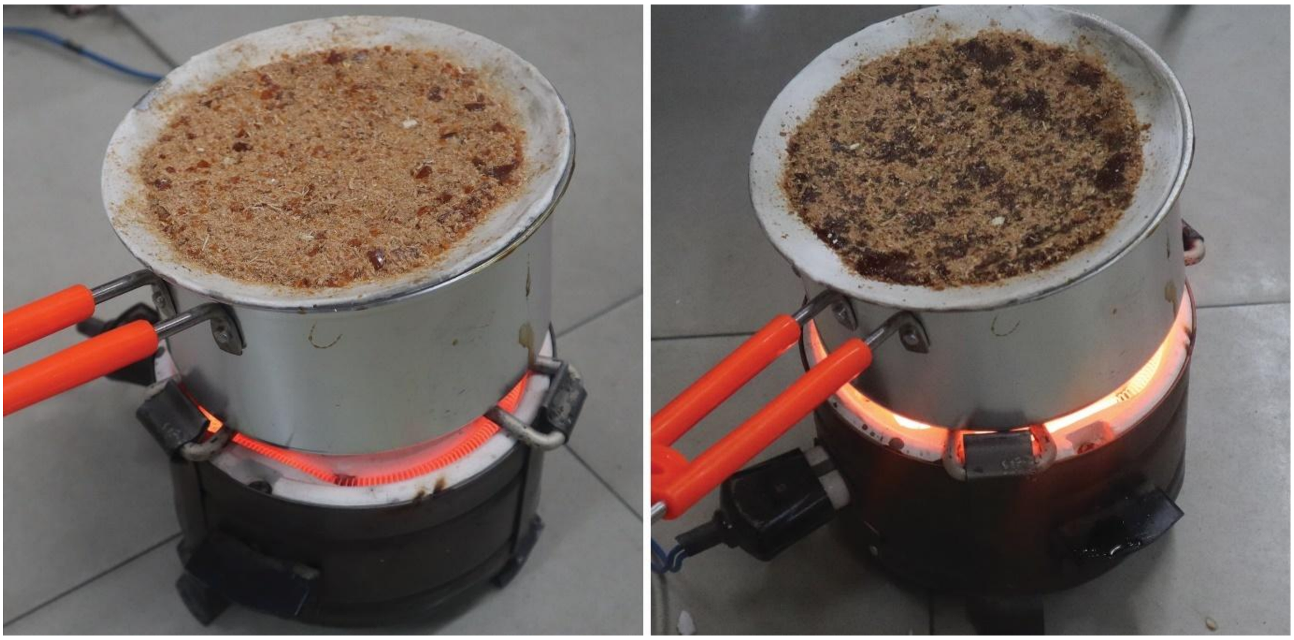

Figure 16: Change in colour of mixture.

Figure 17: Sheet of lac and wood mixture.

As the lac starts melting the colour of the mixture starts changing from light brown to dark brown. Lac acts as a binding agent to bind the wood flour particles together. Berja gums increase the adhesion of lac. The sheet of lac and wood mixture is quite sturdy and it didn't break when dropped from a height of 1.2 meters for 7-8 times.

Coating with Lac

Test-07

This test was done to liquify lac for polishing over various materials. A solution was prepared consisting of 75 gm of lac in 600 ml thinner. The solution was stirred in regular intervals for 1-2 days. Liquid lac was applied on paper using paint brush and the cotton cloth was directly dipped into solution and dried.

Figure 18: Change in lac and thinner solution after two days.

It was observed that lac dissolves completely in thinner and creates a sticky and viscous liquid. When applied on paper the thin layer of lac act as a barrier against water. Similarly, in case of

cotton cloth after applying a single coat of liquid lac its resistance towards water increased.

After drying, the cloth soaked with liquid lac became stiff and retained the form it acquired while hanging. When subjected towards heat the piece of cotton cloth losses its form and becomes flexible but as soon as it cools down it acquires the form given to it. Because of thinner, cloth fibres lose its strength and cloth can be easily torn off like paper but it is still stronger in comparison to paper.

Figure 19: Cotton cloth soaked in liquid lac solution displaying properties like waterproofing.

Test-08

This test was performed to check lac's adhesive properties, increase Paper Mache bowl's life and to use paper as a reinforcing element and check strength of the product.
First, paper pulp is prepared by soaking it in water for a day. Excess water is removed and wheat flour is added by 1/3rd of paper pulp's weight. Liquefied lac is also added as a binding agent. The paste is applied around a bowl and dried in sunlight for 2-3 days. It is then coated with lac buttons by spreading it through hot air gun. The hot air gun's temperature should be maintained between 150 -250°C.

The final outcome displays properties such as lightweight, sturdy, waterproof and smooth surface. The bowl turned out to be quite strong and it didn't break when thrown 2-3 times from a height of 1.2 meters. Lac coating proved to be efficient against water and the bowl was used several times to carry water similar to a regular plastic bowl.

Figure 20: Paper pulp, Dried Paper Mache bowl, Final Paper Mache bowl coated with lac (left to right.)

Additive Manufacturing with Lac

Test-09

This was done to check lac's usability with glue gun. A silicon mould is created for making lac sticks and molten lac is poured in it and dried for half an hour. Lac sticks were then used with glue gun. It was found that lac did come out of glue gun successfully. Although, due to uncontrolled heat provided by glue gun, the molten lac was spreading instead of attaining any height. After sometime because of friction the push mechanism of glue gun stopped working and sticks needed to be pushed manually.

Figure 21: Silicon mould used to make lac stick, using lac stick with glue gun (Left to right).

Outcomes

All the physical characteristics of lac mentioned earlier were confirmed by performing various tests. Still, the durability and performance of these products need to be checked for a longer duration in different climatic conditions. Other than those properties mentioned earlier, few more things noted about lac are as follows –

- **Natural plasticizer: The use of lac as a sealing and barrier agent against environmental conditions such as moisture, air and heat (up to some extent).**
- **Low softening and melting point: Lac soften around 60-70°C and starts melting around 70-80°C when it is in direct contact with heating source. While using hot air gun, more than 150°C is required for melting.**
- **Viscosity: Molten lac is quite viscous in nature and as it starts cooling down when its viscosity increases. Hence, to maintain its fluidity it has to be in constant contact with the heat source.**
- **Flexibility in lac: During the test conducted on lac, water was used to avoid burning lac. Hence, after cooling down it absorbed some amount of water and became more flexible as compared to button lac used earlier.**
- **Thermoplastic: While casting lac, it displayed its ability to become flexible on heating and hardening on cooling, and its ability to repeat the process again.**
- **Recyclable: The thermoplastic characteristic properties and lower melting point of lac makes it easily recyclable when used without any mixture.**
- **Low embodied energy: Because of low melting point, the energy required in modelling lac is quite low as compared to**

other conventional plastics used in model making. Hence, resulting in lower carbon emissions in the environment.

Lac as a modelling material

<table>
<tr><th>Technique applied</th><th>Time, Cost & Labour</th><th>End-of-Life</th></tr>
<tr><td>Hand modelling & sculpting</td><td>More time but easier to make</td><td rowspan="7">• Models once made can be reused again by crushing it into powdered form.
• As lac is a food grade natural plastic, it can be consumed as a food or medicine in smaller quantities.
• Low embodied energy makes it eco-friendly material.</td></tr>
<tr><td>Wire/thread cutting</td><td>Not possible</td></tr>
<tr><td>Casting</td><td>Involves extra time, cost & labour for development of moulds. Once done models can be cooled down to reduce the setting time. Good for multiple repetitive models.</td></tr>
<tr><td>Laser Cutting</td><td>Not possible</td></tr>
<tr><td>FDM 3D printing</td><td>Needs a modified tool to do 3D printing. Not possible with current set of equipment.</td></tr>
<tr><td>Pasting or Assembly</td><td>Done manually</td></tr>
<tr><td>Colour & finish</td><td>Any colour can be mixed to produced desired result and it produces a glossy finish but the matte finish can also be achieved by sanding & buffing.</td></tr>
</table>

Conclusion

The tests showed that the prevalent modelling techniques of casting, hand moulding, sanding and sculpting are possible with lac with a given set of equipment.

Figure 22: Hand sculpted cat model (Top Left), Hand moulded lac birds (Middle), Lac coated bowl (Top right), Lac coated tiles, Lac casted kulhaad (Bottom).

Whereas a modified tool is required to do additive manufacturing with lac. Similar to plasticine, lac models can be reused again to make newer models. Although, the brittle characteristic of smaller lac pieces makes it unsuitable to do detailed or zoom-in modelling but, it can be used in block or form development models. Therefore, lac has the ability to replace conventional materials in block modelling or models produced via casting. Also, the reusability of its models makes the whole process of modelling more sustainable. Thus, encouraging the usage of lac will not only help designers but will also be beneficial to various stakeholders involved in harvesting and processing of lac.

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