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Research and Reviews in Material Science

Volume I

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PREFACE

Welcome to "Research and Reviews in Material Science." In this compilation, we delve into the fascinating realm of material science, a discipline that lies at the intersection of physics, chemistry, engineering, and biology.

Material science is not merely about understanding the properties of matter; it is about harnessing these properties to create innovative solutions to real-world challenges. From nanotechnology to biomaterials, from semiconductors to polymers, the breadth of material science is boundless, offering a playground for discovery and innovation.

This book serves as a testament to the tireless efforts of researchers and scholars who tirelessly push the boundaries of knowledge in this field. Through their rigorous experimentation, meticulous analysis, and creative insights, they unravel the mysteries of materials and pave the way for technological advancements that shape our world.

Within these pages, you will encounter a diverse array of topics, ranging from fundamental research to practical applications. Each chapter represents a journey into the depths of material science, exploring its intricacies and uncovering its potential to transform industries, improve quality of life, and drive sustainable development.

As editors, it is our privilege to present this compilation to the scholarly community and beyond. We extend our heartfelt gratitude to the contributors whose contributions enrich this volume and propel the field of material science forward.

We hope that this book inspires readers to embark on their own explorations of material science, sparking curiosity, fostering collaboration, and ultimately, accelerating the pace of innovation for the betterment of society.

Editors

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CARBON QUANTUM DOTS FROM BIO-WASTE MATERIALS: A REVIEW

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Abstract:

Carbon quantum dots (CQDs) of size less than 10 nm possess fluorescence properties. Such CQDs have excellent characteristics like biocompatibility, photo stability, low cytotoxicity, easy surface modification, high chemical inertness, favorable charge transfer with enhanced electronic conductivity etc. and have wide application range including energy storage devices, bio sensing, bio imaging, disease diagnosis, photo catalysis, etc. In all these fields, CQDs becomes one of potential substitute for semiconductor quantum dots. For production of CQDs, the bio waste materials are mostly preferred as a raw material, due to its abundance, wide availability, low cost and eco-friendly. Owing to this, it is necessary to know the different sources of bio-waste materials and their synthesis techniques for the production of CQDs. In addition, the various factors affecting on the fluorescence properties of CQDs and their application for energy storage devices are briefly outlined in the present paper.

Keywords: Carbon Quantum Dots, Bio Waste Materials, Synthesis Methods

Introduction:

In the field of material science, the new branch of science has emerged as nanoscience. In nanoscience technology, nanoscale material shows unique and amazing diverse properties. The nanoscale dimension particles known as carbon nanotubes (CNTs) were firstly discovered by Lijima in 1991 [1]. The florescence properties of carbon nanoparticles were firstly discovered by Xu *et al.* in 2004 which were accidentally obtained from the purification of single-walled CNTs [2]. In 2006 Sun *et al.* named carbon dots (CDs) as carbon quantum dots (CQDs), which was synthesized by laser ablation of carbon target [3]. Carbon dots are a new member of fluorescent carbon material with the class of nanoparticles with diameter below 10 nm known as CQDs. The unique properties of CQDs include a very strong and tunable fluorescence, excellent photo stability, good dispersibility, biocompatibility, low toxicity, favorable charge transfer with enhanced electronic conductivity, easy synthesis procedures etc. The CQDs are applicable in various field like energy storage devices, biomedicines, optoelectronics, sensors and catalyst. Several studies reported the different synthesis techniques for bio waste derived CQDs with different structures [4- 6]. The structure of CQDs is shown in Figure **1**A. It consist of sp^2 hybrid structure conjugated with carbon core-shell between carbon (core) and organic functional groups (shell) such as N–H,–OH,–C=O, COOH, C=O, and C–N or polymer aggregates [7]. For synthesis of CQDs, bio wastes as a raw materials are preferred due to economic and environmental need. Most of bio waste are derived from agricultural residues, food and animal wastes, forest byproducts, industrial wastes etc. due to its abundance with low cost and eco-friendly.

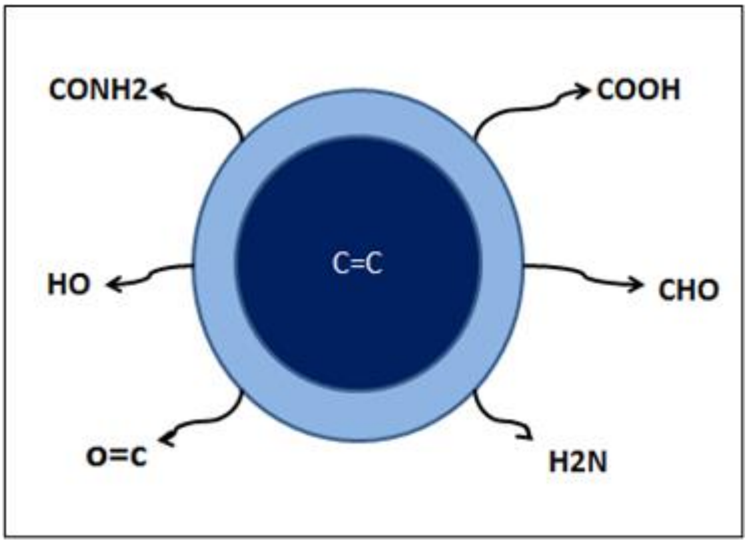

Figure 1: Structure of carbon quantum dot

Recently, quantum dots are attracted extensive attention in various field like electrochemical energy storage and conversion applications due to their large specific surface area, adjustable size, and short ion/electron transport path, non-toxicity, low cost, adjustable photoluminescence, and easy surface functionalization [8–9]. In this field, CQDs and their composites becomes a potential electrode material to enhance the electrochemical performance. Here, the sources of bio wastes materials and some of the different synthesis techniques for CQDs derived from the sources are briefly outlined. Also, the various factors affecting on the fluorescence properties of CQDs and their application for energy storage devices are discussed in details.

Sources of Bio Wastes Materials:

Biomass is one of natural organic raw material used for the preparation CQDs. It is a complex, heterogeneous, biodegradable and bio-organic substance obtained from various sources such as agriculture residues, food wastes, animal wastes, poultry wastes, dairy wastes, forestry wastes and industrial wastes etc. The various bio wastes sources are shown in Figure 2. Bio wastes are renewable, environmentally friendly and abundantly available for C-dots production. But, most of other biomass wastes can causes environmental problems which will affect the human health. These bio wastes are currently discarded, landfilled or openly burned [10]. Recently, researchers reported the utilization of the different biomass wastes as raw materials in the production of CQDs [11-12].

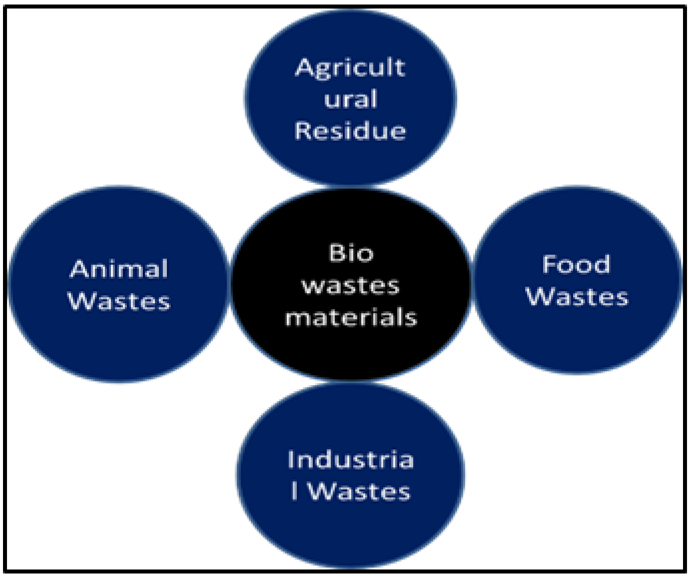

Figure 2: Sources of bio-waste

Synthesis Methods of C-dots (CDs):

Synthesis of carbon dots mainly divided into two main types as top-down and bottom–up approaches. Its schematic representation is shown in Figure 3. The top-down approaches include electrochemical oxidation [13–15], arc discharge [16] and laser ablation [17–18], which involve the exfoliation process of larger carbonaceous materials into nano scale CDs. The synthesis of CDs using top-down approaches greatly limits their practical application due to tough experimental conditions like tedious operation steps and expensive equipment. On the other hand, the bottom-up approaches include the microwave-assisted method [19–21], pyrolysis [22–23], solvothermal method [24–25], ultrasonic method, convert small molecules into CDs via carbonization and passivation. In that, the bottom-up approaches are more advantages due to low cost, easy operation and simple equipment. Hence it is widely used for the synthesis of CDs. Here, some of the methods under bottom-up approaches are discussed for the synthesis of CQDs from bio wastes materials.

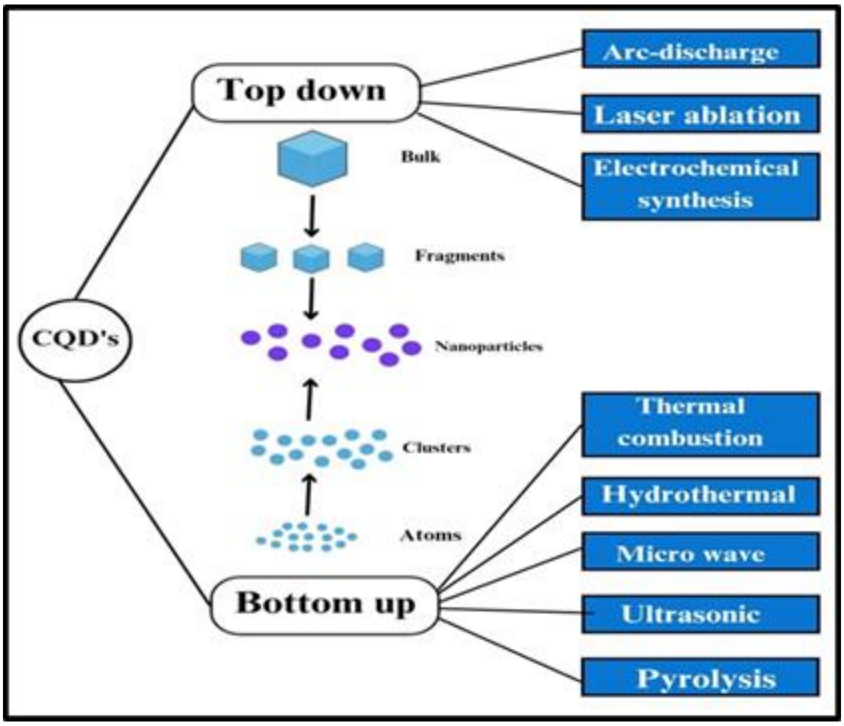

Figure 3: Schematic illustration of CDs preparation via top-down and bottom-up approaches

1. Pyrolysis:

Pyrolysis is a widely used approach for preparation of CQDs. The organic substances are gradually converted into CQDs through heating, dehydration, degradation, carbonization under high temperature either in vacuum or inert atmospheres. High-concentration acids or alkali solutions are generally used in the pyrolysis method to cleave carbon precursors into nanoparticles. All kinds of agricultural bio wastes materials including watermelon peel, sago waste, coffee grounds, plant leaves etc. could be used as carbon sources for producing CQDs by this method [26-27]. The properties of these CQDs can be regulated by changing the conditions of pyrolysis such as temperature, duration and the pH value of the reaction systems [28]. Zhou *.et al.* achieved highest yield of C-dots by pyrolysis of waste watermelon peels under low-temperature followed by filtration [29]. Its synthesis procedure is shown Figure 4. The obtained C-dots possess strong blue luminescence, excellent water solubility, good stability in solutions with a wide range of pH and high [30]. The effects of pyrolysis conditions on the physical appearance, particle sizes and fluorescence intensities of C-dots were studied by Xue *et al.* [31].

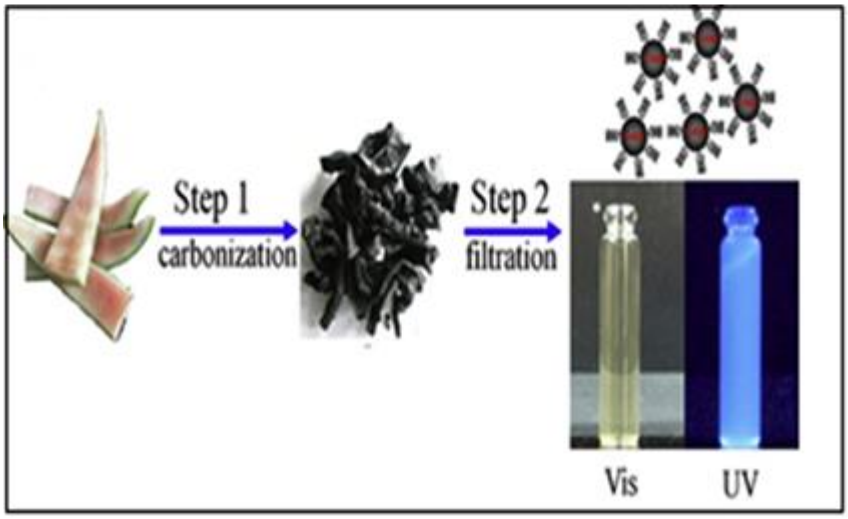

Figure 4: Synthesis of water-soluble C-dots from watermelon peel by Pyrolysis [32]

2. Hydrothermal / Solvothermal Method:

Typically, hydrothermal carbonization (HTC) or solvothermal carbonization is a solution reaction based method. It is a low cost, environmentally friendly and nontoxic route to produce novel carbon-based nanomaterials from various bio wastes precursors. The morphology, structure and size of the particle can be controlled by changing temperature range from 100˚C to 250 ˚C with change in reaction time and concentration of the material. The composition of nanomaterials can be controlled through liquid or multiphase chemical reactions. The different size of CQDs derived from bio wastes materials have successfully synthesized by the researchers using this method [33-34].

R. Atchudan *et al.* reported the fabrication of CQDs from banana peel of particle size ~ 5 nm. The surface of CQDs shows nitrogen and oxygen-containing functional groups. These fluorescent CQDs would be a great potential candidate for bio imaging applications [35]. The synthesis procedure for CQDS from banana peel is shown in Figure 5. Tyagi *et al.* achieved C-dots with spherical morphology and oxygen-rich surface functionalities derived from lemon peel. These C-dots were applied for the determination of Cr^{6+} and the preparation of TiO_2 C-dots for the photo catalytic degradation of methylene blue dye under UV light irradiation [36]. Prasannan *et al.* also reported the synthesis of fluorescent C-dots from orange waste peels under mild conditions by a facile one-pot hydrothermal carbonization method and prepared composited C-dots with ZnO Nanoparticles for photocatalyzing degradation of naphthol blue-black azo dye under UV irradiation [37]. Liu *et al*. synthesized C-dots of quantum yield of 7.1% from bamboo leaves and these C-dots were coated with branched polyethylenimine through electrostatic adsorption for the selective and sensitive detection of Cu^{2+} [38]. Moreover, used food, beverage and combustion wastes as resources to produce highly luminescent C-dots for the fabrication of light-emitting diodes (LEDs). In general, all bio wastes materials selected as the most dependable precursors for the formation of high-quality CQDs with good quantum yield. The synthesized CQDs exhibited excellent fluorescence properties. A green, facile hydrothermal synthesis of CQD was made from cabbage (as a source of carbon) by one step process [39]. The smashed cabbage was heated at 140 _C for 5 h in an autoclave. A dark brown color solution was obtained which was filtered after cooling and centrifuged at 12000 rpm for 15 min.

The purified solution of CQDs was obtained by dialysis using tubular dialysis membrane (MWCO~1 kDa) in the presence of water. The spherical shaped particles with size ranged from 2 to 6 nm were obtained with a quantum yield of 16.5% for luminescence. It may have promising applications in bioimaging due to high biocompatibility, Excellent optical properties and low cytotoxicity. Schematic presentation of the synthesis of CQD from cabbage with the hydrothermal treatment is shown in Cucumber-derived N/S/P-CDs have a graphite-like crystalline structure with lattice spacing of 0.20-0.22 nm [40]. Lemon peels are used to create water-soluble carbon quantum dots (wsCQDs) with spherical shapes and oxygen-rich surface functionalities. CQDs of this type demonstrated excellent photoluminescence (PL) and a quantum yield (QY) of 14% with high aqueous stability. Synthesized was CQDs are immobilized with electrospun TiO2 nanofibers for the photocatalytic activity of methylene blue (MB) which is ~2.5 times higher than that of TiO_2 nanofibers [41]. Sucrose-derived activated carbons exhibited a high specific surface area, large micro pores (widths ranging from 0.7 to 2 nm), and sponge-like morphology [42].

Nitrogen-doped carbon quantum dots derived from a vegetable (green pak choi) yielded 37.5 percent quantum yield after a simple one-pot hydrothermal treatment with no additional solvents [43]. Gedda *et al.* (2016) investigated prawn shell-derived carbon dots as effective sensing probes for Cu2+ detection, demonstrating excellent selectivity and sensitivity towards Cu2+ even at a low detection limit of 5 nm. Synthesized C-dots exhibit specific binding and high selectivity towards Cu2+ and have been successfully used for seawater analysis [44].

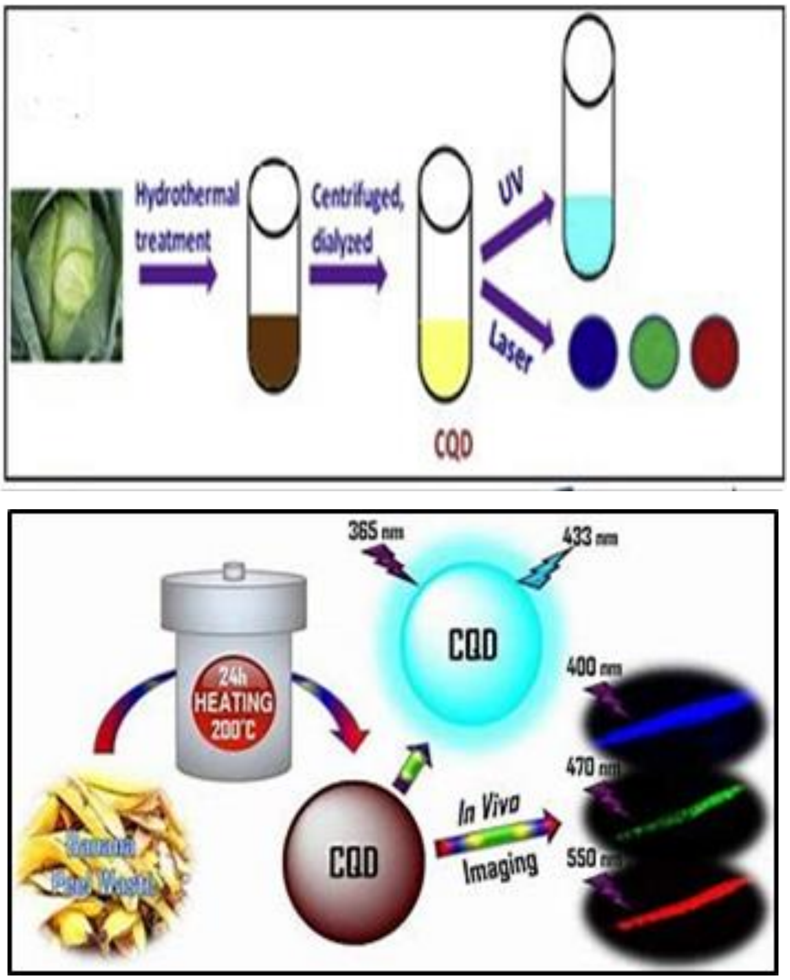

Figure 5: a) Synthesis of carbon quantum dots cabbage

b) Synthesis of carbon quantum dot banana peel [35]

Source	Size (nm)	QY%	Applications	Reference
Cucumber juice	10 nm	3.25	Detection of Hg^{2+}	40
Lemon peel waste	1-3	14	Detecting	41
Sugarcane molasses	1.9	5.8	Detecting Fe^{3+} and cell imaging	42
Green pak choi	1.8	37.5	Detection of $Cu^{2+}$and cell imaging	43
Prawn shells	4	9	Detection of Cu^{2+}	44
Garlic	1-3	10.5	Detcetion of Fe^{3+}	45
Chitosan	4.68	13	Cell imaging	46

Garlic was also used as a green source for the hydrothermal synthesis of carbon dots. Atomic force microscopy (AFM) revealed that the CDs were spherical in shape and ranged in size from 1-3 nm [45]. The same method was used to create CQDs from silkworm. Silkworm contains a high concentration of protein and chitosan, making it a natural carbon source for the synthesis of self-passivation and doped-CQDs. The average diameter of the CQDs obtained was relatively large (i.e., 19 nm), with a size distribution of 13-26 nm and a nitrogen-doping intrinsic of 5.72 percent. Because of its reduced time consumption and precise control of pressure and temperature, microwave treatment produced uniform CQDs with favorable reproducibility [46].

3. Microwave-Assisted Method:

Microwave-assisted is another economical and fast procedure for the production of CQDs as compared to electrochemical and hydrothermal methods. Recently, microwave-assisted production of quantum dots represents growing research field in nanomaterial research. In this method, the electromagnetic waves of wavelength at about 1mm to 10 m are used for preparation of CQDs by breaking chemical bonds within short time using poly ethylene gycol, saccharides such as glucose and fructose, citric acid, urea etc. [47**-49**]. The experimental parameters like microwave power, temperature, irradiation time and solvent play an important role in designing the desired CQDs Li *et al.* reported that the energy gap and structure of CQDs depends on different polarities of the utilized solvents. Thus, due to abrupt heating the as-synthesized CQDs show board size distribution and various functional groups. The CQDs rich with oxygen-containing groups obtained by this technique act as coordination sites for metal ions for the development of CQD-based electro catalysts [50]. Additionally, a recent study investigated the green preparation of CQDs from vaccinium meridionale swartz extract through microwave-assisted carbonization. This method was very distinguished in obtaining large amounts of CQDs with concentrations higher than a mass fraction of 80% in only 5 min. [51]. Only few literatures are available for the microwave assisted synthesis of CQDs for supercapacitor application.

Rice straw was used as a precursor in the synthesis of carbon dots using a mixed solvent of water and ionic liquid (1-allyl-3-methylimidazolium chloride, AMIM-Cl) through microwave hydrothermal microwave hydrothermal treatment. The produced CDs offer a spherical morphology and a high quantum yield of about 22.58 percent [52]. feather produced CDs offering a uniform two-dimensional morphology with a diameter of ~21.5 nm and a height of ~ 4.5 nm having rich oxygen, nitrogen and sulfur atoms with a high photoluminescence efficiency of ~17.1 percent [53]. by microwave has been reported. The BCDs were prepared to have an average particle diameter of 8 nm and fluorescence QY of 13%. BCDs doped with heteroatoms can also be prepared by microwave synthesis. For example, water-soluble N-doped fluorescent BCDs were prepared by microwave method using silkworm chrysalis [54].

Source	Size (nm)	QY%	Applications	Reference
Rice straw	2.50 (CD-250)	22.58	Detection of Fe3+	52
Goose feathers	~21.5	~17.1	Detection of Fe3+	53
Rose	4_6	13.45	Detecting molecules	54
Silkworm chrysalis	19	46	Bio-imaging	55

4. Ultrasonic-Assisted Method:

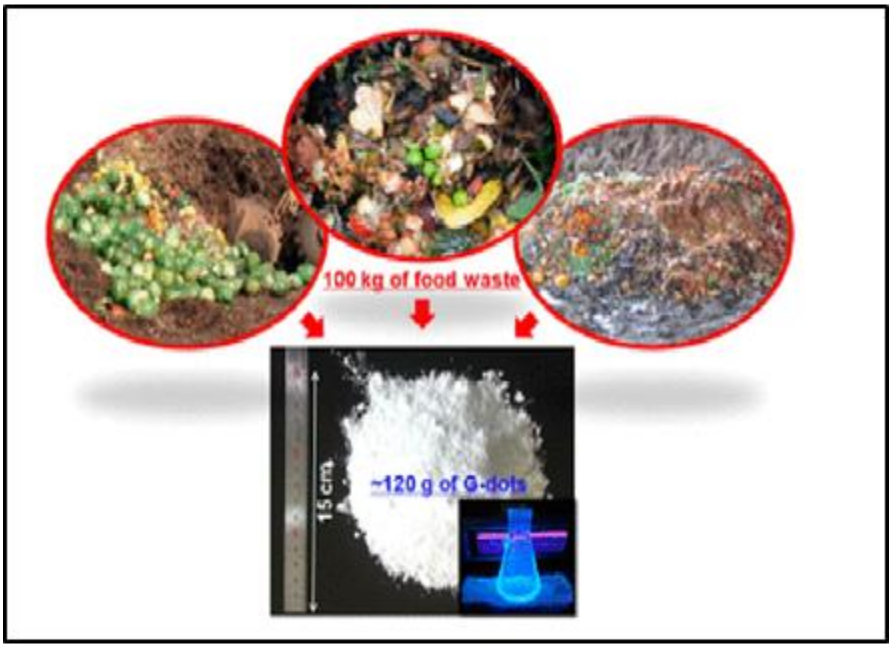

Figure 6: Large-scale synthesis of green C-dots from food wastes [45]

This method is advantages due to the low cost and easy operation for the synthesis of C-dots through the ultrasonic treatment of mixtures of solvents and carbon sources. The properties of C-dots could be regulated by simply adjusting the experimental conditions such as the ultrasonic power, reaction time, the proportion of solvents and materials of carbon sources etc. The sonication parameters such as power, frequency and sonication time are essential to optimize for the preparation of CQDs with desired properties. The photo luminance properties and quantum yield of CQDs can be improved via the doping of metal and other elements. Which further induces the fragmentation of macro carbon materials into CQDs. Kumar *et al.* proposed the synthesis of a hybrid anode Sn@CQDs@Sn through ultrasound techniques. CQDs prepared via this technique were suitable for a variety of applications including superconducting devices and energy storage devices because of their excellent physicochemical and fluorescence properties [56].

Major Factors affecting on the Fluorescence Properties of CQDs:

There are four major factors affecting on the fluorescence properties of CQDs as- quantum size effects, surface defect states, band gap transition and surface passivation [57–59]. In that, surface state is one of the most important mechanisms for explaining the photoluminescence properties of C-dots. Hola *et al.* reported that, surface states of C-dots are mainly induced by surface oxidation of C-dots, which can cause defects on the surfaces of C-dots and hence alter their luminescence. As the degree of surface oxidation of C-dots increases, more surface defects are formed to trap more excitations, resulting in a red-shift of the emission wavelength of C-dots. The different functional groups on the surface of C-dots can significantly affect the fluorescence properties of C-dots. Therefore, surface passivation or surface functionalization plays a vital role in regulating the luminous properties of C-dots. Surface passivation treatment of C-dots can enhance photoluminescence intensity and alter emission wavelength [60].

1. The Impact of Bio Waste Raw Materials:

The bio waste as a raw materials utilized in the synthesis of CQDs can affect the fluorescence properties of CQDs. Himaja *et al.* reported the observable differences in some important properties of the C-dots obtained from cucumber peels and pineapple peels by step-wise procedure for green synthesis of [61]. They also reported that the C-dots obtained from pineapple peels were fully degraded i.e. fungal formed on the surfaces of the C-dots after a few weeks of storage, while the C-dots from cucumber peels show good stability. Therefore, the C-dots synthesized from cucumber peels have greater application potential in fields of organic electronics and bio imaging [62].

2. The Effect of Synthesis Temperature:

The synthesis of fluorescent CQDs from biomass waste materials involves a carbonization process. Since carbonization is an endothermic process depends on temperature during the synthesis of CQDs. At a very high temperature, the carbon source will be over-oxidized, and the surface structure of CQDs will be destroyed, thus causing corrosion in the nanomaterial [63].

3. The Effect of Reaction Time:

The effect of reaction time on the optical properties of CQDs is quite similar to that of reaction temperature [64]. The long reaction time will lead to the destruction of the surface structure of CQDs due to over-carbonization, while a short reaction time will cause carbonization of carbon source, and hence weak fluorescence emission resulted in CQDs. Thus, it should be noted that the effect of reaction time on the optical properties of C-dots is temperature dependent. When the reaction is carried out under a proper temperature then only the optimization of reaction time is significant. But, if the reaction temperature is not high enough, no useful end-product will be obtained even when ultra-long reaction time is adopted [65].

4. The Effect of pH:

As CQDs are obtained from different carbon sources by different synthetic approaches, the influence of the pH value of the solution on their fluorescence emission intensities can be varied. Some CQDs prefer neutral pH, acidic and alkaline pH [66- 67]. Using a hydrothermal method, CQDS possessed plenty of carboxyl and hydroxyl groups on their surface. Due to the protonation and deprotonating of carboxyl groups under different pH conditions and the resulting change in electrostatic charging property shows the fluorescence emission intensity of the C-dots decreased gradually as the pH value increased from 4 to 12.

5. Effect of Surface Passivation:

The surface passivation is the process in which CQDs are protected to increase its optoelectronic properties. The fluorescence quantum yield of bare C-dots is generally quite low without any surface modification. The Surface passivation or functionalization has advantage in bio analytical tests for improvement of the fluorescence emission intensity of C-dots. To enhance fluorescence emission intensity, the surface passivation of C-dots should decrease the surface defects and hence increase the exciton-hole recombination probability, which will prevent C-dots from agglomeration. The surface passivation includes two major approaches that cover bare C-dots with some long-chain agents and other, oxidizing the surfaces of C-dots with strong acids. Due to the usual presence of long-chain carboxylic acids and some other functional substances in carbon sources, carbonization and passivation occur at the same time during the synthetic process of C-dots from biomass waste. As a result, CQDs synthesized from biomass wastes are often self-passivated and their surfaces are improved with hydroxyl, amine, carboxyl or thiol groups [68].

Properties of C-dots obtained from Biomass Waste Materials:

The CQDs becomes advantages due to easy operation, low cost, excellent waster-solubility, outstanding photo stability, stable photo luminescent, low cytotoxicity, good biocompatibility and easy surface functionalization. Some of the structural and optical properties of CQDs are discussed briefly as-

1. Structural Property

CQDs are generally three-dimensional clusters with a spherical-like structure composed of carbon atoms and tiny amounts of molecules. The inner parts of the three-dimensional clusters contain mainly SP^3 hybridization carbon atoms and a small portion of SP^2 hybridization carbon atoms. The crystal lattices of C-dots are well constant with those of amorphous carbon and graphite [69]. C-dots usually have a particle size of less than 10 nm, and therefore exhibit "quantum size effect. When the particle size of C-dots increases, their maximal fluorescent emission wavelengths show a red-shift. C-dots mainly contain elements of C, H, O and N. The proportions of these elements are different for different synthetic methods of C-dots. The surface passivation and some other treatments can move the surfaces of C-dots with amino, hydroxyl and carboxyl functional groups to improve the water solubility of C-dots. The surface functionalization becomes an important foundation for extensive application of C-dots.

2. Optical Properties:

2.1. UV-Absorption Property:

The C-dots have broad and strong absorption bands in the ultraviolet to visible wavelength region. As C-dots were prepared by different synthetic approaches from different precursors and dispersed in different solvents, then their absorption spectra are obviously different from each other. In general, C-dots have one or more absorption peaks located at the ultraviolet to visible wavelength region [70]. The absorption peak in the wavelength range of 220~270 nm can be roughly attributed to the transition of C=C and C=N bonds. The peaks located at the wavelength range of 280~350 nm is corresponding to the n-transition of C-O and C=O bonds. The absorption peaks lying in the region of 350~600 nm is generally related to the transition of functional groups on the surfaces of C-dots [71].

2.2. Fluorescence Property:

The fluorescence property is one of the most important features of C-dots / CQDs, which will affect their application in many fields. The C-dots/ CQDs possess excellent fluorescence properties including wide excitation spectrum, narrow emission spectrum, size-dependent, fluorescence emission, good fluorescence stability, up-conversion luminescence and strong resistance to photo bleaching. Though quantum confinement effect, emissive traps, the exaction of carbon, passivated surface defects, oxygen-containing groups or aromatic structures, and luminescence mechanism of C-dots has not yet been clearly understood. Zhang *et al.* synthesized C-dots from polystyrene foam waste found that the fluorescence emission peak position was affected by the type of organic solvent used to extract the C-dots. Ding *et al.* speculated that the surface passivation by different organic solvents form different surface defects on the surface of C-dots and introduced different emission sites upon C-dots, leading to the changes in the peak position and intensities of the fluorescence emission spectrum of C-dots [72].

Applications of CQDs in Energy Storage Device:

The CQDs have variety of unique properties. Therefore, CQDs were more popular in various energy-related field such as supercapacitor, photovoltaic, batteries, water splitting and photo detectors. They can sustain high power output for long duration. In that, supercapacitors have received a lot of credit due to long life cycle, fast charge and discharge higher power density and environmental friendliness [73]. For supercapacitors, the nanomaterial like CQDs based electrodes with a higher specific capacitance and longer period stability becomes a good choice. Here, some of research articles for supercapacitor are reviewed. The CDs-based electrodes can provide ultra-high capacity and maximum efficiency due to their excellent properties such as higher electronic conductivity, lots of active sites, high surface area, significant wettability in different solvents, and adjustable band gap [74]. Carbon /graphene quantum dots (CQDs or GQDs) retain the characteristics of carbon materials as stable chemical properties and have quantum tunneling effect, size effect, and surface effect. It has a strong adsorption capacity for electrolyte ions, and a wide range of development prospects in SCs [75].

Surface-area-based carbon materials with higher specific capacitance and longer cycle stability. Thus, in energy-storage applications, the CQDs have been used due to their shape and tunable size properties and high electrical conductivity [76-78]. Synthesized CQD-MnO_2 nanostructure from a sustainable bio waste source by employing an environmentally friendly approach [79]. The CQD-MnO_2 exhibited high surface area and improved electrical conductivity than pristine MnO_2, which is reflected from the highly conductive CQDs. The CQD-MnO_2 nano hybrid used as an electrode in symmetric supercapacitors show a specific capacitance of 189 Fg^{-1} with a long cycle life due to admirable Columbic efficiency and quick current voltage response imitated from the electrochemical analysis. The CQDs can increase the electrical conductivity of the metal oxide/sulfide composites and gives better electrochemical properties for energy-storage devices [80-82].

Conclusions:

Biomass waste is abundant and widely distributed in the natural and living environment. From the literature, some of the methods under bottom-up approaches are reviewed for preparation of fluorescent C-dots from biomass wastes and analyzed that the size of CQDs and surface functional group can affect the fluorescence intensity of C-dots. The use of CQDs or CQDs-modified nanomaterials have greatly applicable in various applications. Among all above synthesis methods, hydrothermal method is a low cost, environmentally friendly and nontoxic route to produce novel carbon-based nanomaterial from various bio wastes precursors. Therefore this method becomes easy to control the composition and morphology of CQDs. Since CQDs have a large surface area and uniform particle size. The size, shape, surface functional groups of C-dots are essential for modification of their properties. The researcher also proved CQDs and their composites for Supercapacitor can provide ultra-high capacity and maximum efficiency due to their excellent properties. Thus, for energy storage devices like supercapacitors, the CQDs and their composites based electrodes becomes a good choice for enhancing the higher specific capacitance and longer period stability.

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BAMBOO: AN EMERGING SUSTAINABLE CONSTRUCTION MATERIAL

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Introduction:

Bamboo has been recognized for its adaptability and sustainability for centuries, making it a vital component of human society. The use of Bamboo has been recorded in many cultures in Asia, Africa, and the Americas. It has been used for building, crafting, and even as a food source. Bamboo is a member of the Poaceae family of grasses and has many amazing qualities, including strength, flexibility, and quick growth [1]. Bamboo is strong, lightweight, and naturally resistant to fungi and pests. In many communities, bamboo has great cultural and symbolic significance. Strength, resiliency, and adaptability are frequently linked to it. Bamboo is considered a symbol of longevity, prosperity, and humility in Asian civilizations. Bamboo has become more popular as a sustainable substitute for traditional building materials in recent years. Because of its strength, adaptability, and eco-friendliness, it may be used for a variety of purposes, such as flooring, furniture, housing, and decorative objects [2].

Bamboo is a very sustainable construction material that provides several environmental benefits when compared to standard materials such as wood, steel, and concrete. Bamboo is one of the world's fastest-growing plants [3], reaching maturity in about three to five years. Because of its high growth rate, it may be harvested sustainably without depleting natural resources over time. Traditional construction materials, such as wood harvested from slow-growing trees, take decades to mature. The use of pesticides, fertilizers, and other chemicals is usually kept to a minimum when growing bamboo. It is a low-impact agricultural resource since it uses less water than many other crops. Additionally, the broad root systems of bamboo contribute to soil health and help to minimize soil erosion. During its growing season, bamboo can absorb large volumes of carbon dioxide from the atmosphere [4]. Because of this, bamboo forests reduce greenhouse gas emissions and hence serve as carbon sinks, assisting in the fight against climate change [5]. In comparison to many conventional building materials, this one has a better potential for sequestering carbon. In comparison to conventional building materials such as steel, concrete, and wood, bamboo frequently exhibits better sustainability results. For transportation, processing, and cultivation, less energy and resources are needed. Furthermore, bamboo is a more sustainable material for long-term building projects due to its quick growth and renewability.

Bamboo: Harvesting, processing, and treatment

To improve bamboo's strength, resilience, and appropriateness for building, it goes through multiple steps of processing. Bamboo is usually harvested at a point of maturity that varies based on the species and climate in the area. To achieve the best strength and quality, bamboo poles must be chosen at the proper stage of growth. Bamboo is treated in several ways to increase its resistance to environmental conditions, rot, and pests. To get rid of fungi, microbes, and pests, bamboo poles are heated to high temperatures [2]. Additionally, heat treatment aids in lowering moisture content and boosting dimensional stability. Bamboo can be treated with preservation chemicals to ward off rot and insect infestation. These solutions frequently include borates or other eco-friendly substances. Bamboo may occasionally undergo pressure treatment, which involves applying intense pressure to drive preservative liquids into the fibres of the bamboo. Deep penetration of the preservatives is ensured by this approach, providing long-lasting protection.

To lessen moisture content and improve strength and stability, bamboo poles are dried after treatment. During construction and storage, proper drying stops warping, cracking, and deterioration. Bamboo must be conditioned to reduce dimensional changes that occur after installation. Bamboo must be acclimated to the ambient humidity levels at the construction site. Bamboo poles are trimmed to the appropriate lengths for construction purposes. To achieve homogeneous sizes and forms appropriate for different structural and decorative features, this may entail methods like splitting, sawing, or milling. Bamboo surfaces can be treated with coatings or finishes to improve their appearance, resilience to weather, and longevity, depending on the application. Paints, varnishes, oils, and natural sealants are examples of finishing materials [6].

Structural Characteristics of Bamboo

Bamboo has exceptional structural qualities that make it a great material for a variety of building uses. Bamboo's strength, flexibility, and load-bearing capabilities are among the structural qualities that make it suitable for a variety of construction applications [7]. Bamboo is extremely strong for its weight, matching or surpassing the strength of many conventional building materials like steel and wood. It is an effective material for structural components because of its remarkable strength-to-weight ratio [8]. Bamboo's strength is a result of its distinct fibrous structure, which consists of long, parallel fibres that run the length of the plant.

Bamboo is well known for its natural flexibility, which enables it to withstand torsional and bending stresses without breaking. This adaptability is essential for withstanding earthquake activity, wind loads, and other dynamic pressures that are frequently encountered in construction [9]. Bamboo's inherent flexibility increases structural longevity by fortifying its resistance to impact and vibration. Bamboo has a high load-bearing capability in proportion to its mass and size. Bamboo buildings can handle heavy weights because of their hollow internodes and cylindrical shape, which promote effective load distribution. By optimizing structural designs and joining procedures, bamboo's load-bearing capability can be further boosted through appropriate design considerations.

A range of testing techniques, including bending, compression, and tensile tests, are utilized to evaluate the structural characteristics of bamboo and verify adherence to pertinent guidelines and regulations. Guidelines for assessing bamboo's mechanical performance can be found in international standards, such as those set by ASTM International and the International Organization for Standardization (ISO) [10].

Bamboo in Architectural Design

Bamboo is a useful material in architectural design because of its adaptability, sustainability, aesthetic appeal, cultural value, and inventive possibilities. Using the special qualities of bamboo, architects can design built environments that are robust, sustainable, and culturally rich all of which promote a more peaceful coexistence between people and the natural world. Bamboo's strength, elasticity, and adaptability give architects a plethora of options. It can be incorporated into many different architectural aspects, such as partitions, roofing, flooring, cladding, and decorative elements [1]. The eco-friendly qualities of bamboo are consistent with green building ideas. Designers and builders who are concerned about the environment can choose it because of its quick growth, minimal environmental impact, and capacity to sequester carbon. Bamboo gives architectural spaces a warm, tactile, and visually stimulating look by incorporating an organic and natural feel. Warm tones and unique grain patterns enhance the overall ambience of buildings and interiors by fostering a sense of harmony with nature. By pushing the limits of conventional building methods, architects are investigating novel ways to incorporate bamboo into their designs. To produce creative, affordable, and sustainable architecture solutions, involves experimenting with bamboo composites, engineered bamboo products, and modular bamboo systems [7]. The concepts of biophilic design, which aim to improve productivity and well-being by fostering a connection between residents and the natural world, are in line with bamboo. A feeling of biophilia can be evoked by incorporating bamboo features into architectural design, which can improve general well-being and pleasure.

Regulations for Bamboo Construction

Regulations for bamboo construction are critical in promoting bamboo as a sustainable and viable building material while also ensuring the safety, quality, and longevity of bamboo constructions. Compliance with these requirements promotes confidence in bamboo construction and contributes to its wider acceptance as a standard building material. There are rules governing bamboo construction in several national building codes. To guarantee that bamboo constructions fulfil safety regulations, these codes may set standards for structural design, material quality, and building techniques. International standards for bamboo building have been produced by organizations like the International Network for Bamboo and Rattan (INBAR) and the International Organization for Standardization (ISO) [2]. These guidelines address several topics, such as the preservation and management of bamboo and structural design. Certain nations have created national norms that are exclusive to the use of bamboo in buildings. The types of bamboo that are readily available, the local climate, and customary building methods may all be covered by these guidelines. Quality control measures are frequently incorporated into regulations during the cultivation, processing, and building of bamboo. This guarantees that the bamboo used in building satisfies requirements for strength, durability, and insect and decay resistance.

Guidelines for structural design, including permissible stresses, load combinations, and connections, are commonly included in standards for bamboo construction [8]. Engineers and architects can guarantee the safety and durability of bamboo structures by following these principles. Bamboo may need to be treated or conserved by regulations to increase its resilience against fungi, insects, and rot. Heat treatment, chemical treatments with non-toxic preservatives, or pressure impregnation are some examples of treatment techniques. Some regulations mandate training and certification programs tailored to bamboo construction for builders and construction personnel. By doing this, you can make sure that building procedures follow safety regulations and recommended bamboo handling techniques.

Economic Viability of Bamboo

Bamboo is economically viable because of its adaptability, quick growth, cheap input costs, possibilities for job creation, export potential, advantages for the environment, and support from laws and incentives. Bamboo has the potential to significantly contribute to both economic prosperity and sustainable development if these benefits are fully realized [4]. Bamboo is a multipurpose material that may be used in building, furniture making, paper manufacturing, textiles, and handicrafts, among other industries [2]. Its adaptability generates a variety of revenue streams, which increases its economic potential. When considering other crops or timber species, the cost of inputs for bamboo growth is comparatively lower. Its ability to flourish in a variety of settings with less need for pesticides and fertilizers lowers production costs and makes it more appealing to farmers and growers financially. Employment possibilities are created across the value chain by the cultivation, harvesting, processing, and manufacturing of bamboo, especially in rural areas where there may not be many other options for subsistence. This promotes economic empowerment and the reduction of poverty. Products made of bamboo have great export potential, particularly in regions where consumers are looking for eco-friendly and sustainable goods. Exporting goods made of bamboo can increase economic growth and yield foreign exchange profits.

The economic viability of bamboo can be increased by government regulations and incentives that support its processing, utilization, and cultivation. This covers policies like tax breaks for businesses that rely on bamboo, financial aid for bamboo farmers, and regulatory frameworks that are conducive to the industry. New economic opportunities can be created through ongoing research and innovation in bamboo processing technology, product development, and farming methods [2]. Putting money into research and development can help bamboo find new applications and increase its marketability.

Bamboo in Disaster Resilient Construction

Bamboo has several benefits for building that is resilient to disasters, such as strength, flexibility, lightweight, quick reconstruction, accessibility locally, cost-effectiveness, fire resistance, sustainability, and community involvement [6]. By including bamboo into disaster risk reduction plans, communities that are already at risk can become more resilient and the effects of natural catastrophes on lives and livelihoods can be lessened. Bamboo is exceptionally strong and flexible, which helps it withstand a variety of natural calamities like storms, cyclones, and earthquakes. Strong winds and seismic forces cannot destroy bamboo constructions because of its elasticity. Due to the ease of construction and the availability of bamboo, bamboo structures can be swiftly built or rebuilt following a disaster. This quick reconstruction lessens the disturbance that comes with calamities and speeds up community recovery. In many disaster-prone locations, especially in tropical and subtropical zones, bamboo is widely available. Its accessibility locally lowers the need for imported building materials and shipping expenses, making it an affordable choice for construction that is disaster-resistant. Bamboo is a low-impact, environmentally friendly, and sustainable building material. It is an environmentally sound option for buildings that are disaster-resilient due to its quick growth rate, high capacity for sequestering carbon, and ability to stop soil erosion.

Challenges and Future Directions in Bamboo Construction

To progress bamboo construction techniques, increase structural design, improve treatment procedures, and discover novel applications for bamboo, more research and development funding is required. National and international standards for bamboo construction are still required. Closing this gap will guarantee bamboo building durability, safety, and quality. Building capacity and knowledge of bamboo construction methods among builders, engineers, architects, and craftspeople is crucial. Initiatives for knowledge sharing, workshops, and training programs can aid in the development of the required abilities.

It is still difficult to dispel the notion that bamboo is a "poor man's material" and to get major construction markets to accept it. Campaigns for education and awareness as well as the display of prosperous bamboo projects can influence public opinion and spur demand. Bamboo is widely employed in rural regions, but its adoption in urban construction projects is hindered by issues like regulatory impediments, land limits, and low knowledge. Bamboo's market potential may be increased by looking for creative ways to integrate it into high-rise structures and urban infrastructures [2]. Changes in rainfall patterns, temperature swings, and increasing insect pressure are just a few of the difficulties that climate change presents for bamboo construction and cultivation. Creating bamboo species and building methods that are climate-resilient can help lessen these difficulties.

Through encouraging laws, grants, and other initiatives, governments can significantly contribute to the growth of bamboo building. Market expansion can be accelerated by laws that promote environmentally friendly building materials and provide incentives for the production and use of bamboo. To advance bamboo building globally, cooperation between governments, non-governmental organizations, academic institutions, and industry partners is essential. It is possible to overcome common obstacles and expedite progress by exchanging best practices, lessons gained, and information.

Conclusion:

The construction of bamboo structures exhibits great potential as a robust and sustainable building material. To fully realize this potential in the future of construction, it will be imperative to address the obstacles associated with bamboo construction and optimize its benefits through legislative support, industry collaboration, and ongoing research. Bamboo building has many benefits that make it a desirable choice for durable and sustainable structures. It is suitable for a wide range of applications, from high-end architectural projects to affordable homes, thanks to its exceptional strength, flexibility, and quick growth rate. Furthermore, bamboo's low environmental effect, widespread availability, and reasonable cost make it a desirable substitute for traditional building materials.

There are certain issues and drawbacks with bamboo construction as well, which need to be solved. These include the requirement for thorough norms and laws, dispelling myths about the industry, boosting supply chain management, and fostering the growth of talents in bamboo building methods. Furthermore, bamboo treatment methods and species selection require continuous study and innovation because of climate change and potential durability difficulties in specific climatic situations

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PUMPKIN SEED OIL AS AN ALTERNATIVE PRODUCTION OF BIODIESEL

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Abstract:

Vegetable oil's physicochemical properties are crucial in determining whether it is suitable for a given appliance. These characteristics uniformly suggest that vegetable oil can be stored under various environmental and packaging conditions. The oil was extracted from pumpkin seeds using the Soxhlet extraction method, and its physicochemical characteristics were examined for the outcome of the variety factor over three replications. As a result of the current situation, the cost of all commercial fuels is high, rising day by day more intensely than ever before, and their use directly contributes to environmental pollution, which unavoidably accelerates global warming. In the current study, the dissimilar seeds were used to produce biodiesel from soybean (*Glycine max*), peanut (*Arachis hypogaea*), and pumpkin (*Cucurbita pepo*). After drying and pressing the corresponding seeds, the oil was extracted. It was estimated that the extracted oil represented an overall yield percentage of 83.00% for pumpkin. It was determined that the yields for peanuts and soybeans were 85.00% and 79.00%, respectively. Peanut oil yield was found to be higher at 85.00%. Numerous oil parameters were predicted. pH, color, appearance, protein and fiber content, gravity, solubility, moisture content, and fat content in water were the test parameters that were predicted. Additionally, pumpkin seed oil was used to make biodiesel, which was then characterized through flame testing and a GC-MS analysis report. Palmitic acid (54.64%), oleic acid (28.38%), and EPA (4.72%) were the main fatty acids present. The most biodiesel possible can be produced in a profitable manner with the help of this active content.

Keywords: Soybean Oil, Biodiesel, Pumpkin Seed Oil, Physicochemical Properties

Introduction:

Biodiesel is a locally produced, renewable, decomposable fuel made from used restaurant grease, animal fats, or vegetable oils. Both the biomass-based diesel and the overall progressive bio fuel requirement of the renewable standard fuel are met by biodiesel [1]. This biodiesel was developed by the inventor Rudolph Diesel in the 1890s and has costumed a superior of strength, dependability, and eminent fuel economy on a global scale. Research conducted in Belgium in the 1930s led to the development of modern biodiesel, which involves transforming vegetable oil into a substance known as full of fat acid methyl esters. However, biodiesel production was not widespread in Europe until the late 1980s. The diesel engine was developed specifically to improve upon the late 1800s' dangerous and inefficient steam engines. Diesel has gained widespread recognition for the innovative ways in which his engine could use various types of petroleum [2, 3].

Because of deplete deliveries and the gasolines' contributions to the accumulation of carbon dioxide in the earth's atmosphere, it is now widely acknowledged that the continued use of gasoline source fuels is unsustainable [4]. The increased atmospheric concentrations of carbon dioxide and water vapor brought on by the large-scale burning of fossil fuels are thought to be the cause of the global warming. Daily hazardous emissions into the air result in an increase in the amount of greenhouse gases in the atmosphere [5,6]. Another fuel made from regenerative herbal oils, animal butters, or used cooking oils is biodiesel, which is created through the chemical process of transesterification. A persuasive mission for kingdoms is the discovery of alternative energy sources, particularly for nations lacking in conventional fuel wealth. Herbal oils were used as natural biodiesel fuels in emergency situations in the 1930s and 1940s. Recent years have seen a significant increase in the demand for energy due to the current industry's rapid growth [7].

Because of a few factors, biodiesel seems to be a lovely energy source. It is a renewable energy source that might be offered sustainably. It has a number of beneficial ecological characteristics, which leads to the same low sulfur content and no net improvement in carbon dioxide discharge [8,9]. Compared to diesel fuel, it has a lower flash point. Unlike diesel fuel, its production profile is transparent. It can be used as scrap in diesel engines that need to be modified and can be effectively blended with petro-diesel fuel. Biodiesel produced from animal fat, cooking oil, and oil from oil crops is unable to satisfy even a small portion of the current demand for transportation fuels [10]. For biodiesel, the production cost is elevated. The quantity of biodiesel could take the place of conventional fuel.

The effect of salinity and pH on the development of pumpkin seeds is examined in the current study. The development was evaluated for biodiesel production by measuring the absorbance at 750 nm and the colorant concentration, and extracting the entire lipid [11,12]. The primary biodiesel attributes mentioned in the creative writing include its local origin, which would help reduce a nation's reliance on petroleum imports, its biodegradability, high spark point, and inherent grease in the neat form reported by Moser [13]. The advantages of biodiesel over conventional fuel include its superior biodegradability, higher ignition efficiency, lower sulphur and aromatic content, and higher cetane number. According to, biodiesel has a lot of potential as a substitute fuel in compression ignition engines. It is estimated and characterized that India consumes petroleum products at a proportionately high rate. Transportation, 51% production of gasoline, diesel, fuel oil, natural gas, and naphtha, 14% marketable and other products, 13% internal products (kerosene and LPG), 18% from agriculture (diesel), and 4% other products.

Materials and Methods:

The local market and garden were used to obtain the pumpkin (*Cucurbita pepo*), soybean (*Glycine max*), and peanut (*Arachis hypogaea*). The pumpkin fruits were disassembled, and the seeds were taken out for additional processing [14]. To clean and get rid of the microbial contamination, the seeds were washed in distilled water for a minute and then with 1% regular brackish water. With the help of a blade, the seeds were removed, and it was then dried at 400°C for roughly 72 hours. The low temperature was maintained to stop low temperature stable volatile constituents in the seeds from evaporating. To prepare the seeds for oil extraction, the seeds were broken into smaller pieces and ground into coarse particles. The dried seed of the peanut and soybean was used right away to produce coarse particles.

Extraction of Oil from Various Powdered Seeds:

The soxhlet extraction method was used to extract the various seeds. The ground seeds (100g) were precisely measured into the soxhlet extractor's thimble, and 300ml of n-hexane were added to the flask at the bottom of the apparatus. The thorough soxhlet extraction was then mounted on a heating pad with an 80°C temperature setting. The extractor setup was left in place for 6 hours at this temperature. The percentage (%) of each seed's oil production was calculated [15].

Physico-Chemical Analysis of Oil Extracted from Various Seeds:

The parameters include pH, color, appearance at 20°C, yield percentage, content of fiber, fat, moisture, and protein, as well as gravity. The solubility in ethanol and water was established [16]. Each seed sample was examined for its level of acidity using a pH meter. Each oil's color was foreseen using a standard color chart. Visible prediction was used to estimate the oil's appearance.

Production of Biodiesel:

The 1984 Freedman method was used for the production. Using the traditional process, biodiesel (FAME- fatty acid methyl esters) was produced from pumpkin seed oil. Comparing the extracted biodiesel allowed for the finer characterization of the highest producer.

Biodiesel Characterization:

The flash test, which determines the presence of FAME constituents detailed in the discharge progression in locomotives and machinery, served as the initial and fundamental assenting test for the biodiesel. An Rf value, a chromatographic dimension, can also be made available through TLC. The solvent phase was supplemented with 9:1 (hexane:diethyl ether) or 85:15:1 (petroleum ether:diethyl ether:acetic acid). A research method known as GC-MS combines the structures of mass spectrometry and gas chromatography [17,18].

Result and Discussion:

The three types of seeds that were gathered were identified at the species level as Peanut, Soybean, and Pumpkin (*Cucurbita pepo*), respectively (*Arachis hypogaea*). The extract oil's estimated yield for the entire sample was found to be 83.00% pumpkin by weight. The yield percentages for peanuts and soybeans were examined at 85.00% and 79.00%, respectively. It was discovered that peanut extract had a higher extract yield for oil [19].

The physical and chemical parameters were analyzed, and table 1's results were tabulated. Pumpkin was found to have a low pH and to be slightly acidic, and the color of peanuts was determined to be a strong yellow [20,21]. The appearance at 20^{o}C produced translucent soybeans, high pumpkin and peanut seed extraction thickness, and other results. 1.16 percent moisture was found to be present in pumpkin [22,23]. According to estimates, peanuts and soybeans both have high protein and fiber contents. In soybeans, the gravity is high. Every seed oil has some water solubility. Salinity and pH are the two environmental factors that have the biggest impact on how an organism develops. The growth and biochemical makeup of microbial or plant samples can significantly change in response to small changes in these conditions [24,25].

Table 1: Analysis of Physico-chemical parameters

Parameter	Pumpkin	Peanut	Soybean
pH	5.6	6.7	6.5
Color	Yellow	Strong yellow	Yellow
Appearance at 20°C	thickness Oily	thickness Oily	Transparent, Oily
Percentage yield	83.00	85.00	79.00
Moisture content	1.16 %	1.31 %	2.39 %
Protein content	0.83,	0.97	0.9
Fiber content	0.025	2.099	2.133
Fat content	12 gms	93 gms	95 gms
Gravity	0.8	0.9	0.92
Solubility in water	Partially Soluble	Partially Soluble	Partially Soluble
Solubility in ethanol	Soluble	Partially soluble	Partially soluble

Biodiesel Production Estimation:

Additionally, the Physico-chemical properties of the pumpkin seed oil were determined for use in the production of biodiesel. The FAME that was obtained was intended for GC-MS analysis in order to classify the fatty acids present in it[25]. The fatty acid sketch was obtained, and the most abundant fatty acid was found to be palmitic acid, which makes up 54.64% of the total FAME and is followed by oleic acid, which makes up 28.38% of the FAME. The third-highest fatty acid was eicosapentaenoic acid, which had a 4.72% concentration (Table 2). By imagining TLC plates, the TLC examination preliminary supports the existence of methyl ester groups' existent in the biodiesel based on the physicochemical characterization. The GC-MS analysis of the biodiesel revealed the various fatty acid groups still present in the FAME biodiesel as well as their chemical configurations.

Table 2: Pumpkin seed oil fatty acid profile

S. No.	Fatty acid profile	Percentage %
1	Capric acid	0.06
2	Myristic acid	7.0
3	Pentadecanoic acid	1.0
4	Palmitic acid	54.64
5	Palmitioleic acid	0.51
6	Margaric acid	0.57
7	Stearic acid	0.59
8	Oleic acid	28.38
9	Linoleic acid	0.38
10	Arachidonic acid	1.30
11	Eicosapentaenoic acid	4.72

The flame test, which validates the presence of methyl ester groups in the biodiesel, was the first and most fundamental assenting investigation. This flame test, which is shown in the figure, thus verified the presence of the methyl esters group in the biodiesel. This demonstrates that FAME (fatty acid methyl esters) was a key component in the development of engines and other machinery during the combustion of biodiesel. Another important confirmatory test for biodiesel was thin layer chromatography, which confirmed the presence of methyl esters in the fuel through the separation of the compounds in the TLC plates. The retention time (RT) of Standard hydrocarbons is used by the GC-MS statement to distinguish different hydrocarbon groupings. The analysis identified 15 significant fatty acid components that are present in the biodiesel sample as hydrocarbon chains (Table 3).

Palmitic acid (54.64%), oleic acid (28.38%), and EPA (4.72%) were the three main fatty acids found. The upcoming use of biodiesel limits the use of fossil fuels while also reducing hazardous air pollutants that are released without restriction during the burning of conventional fuels, which are therefore referred to as "green fuel." The production of the characterized biodiesel from the pumpkin seed was successful, and the GC-MS confirmed it. When compared to fossil fuels, it was determined from the analysis that it can produce less toxic waste in the atmosphere.

Table 3: Determination of Fatty acid groups under GC-MS

S. No	Fatty acid name	Retention time (RT)	Ions	Molecular weight (g/mol)	Molecular formula
1	9-Amino-1,8-Dimethyl-3,6-diazahomoadamantane	25.65	132	181.278	$C_{10}H_{19}$
2	Heptadecanoic acid	28.33	53	270.457	$C_{17}H_{34}O_2$
3	Octadecyl ester	30.03	111	536.9557	$C_{36}H_{72}O_2$
4	Decane	7.55	60	142.282	$C_{10}H_{22}$
5	Nonanoic acid, methyl ester	12.92	82	172.2646	$C_{10}H_{20}O_2$
6	9-Hexadecenoic acid	17.09	227	254.4082	$C_{16}H_{30}O_2$
7	Dodecanethioamide,N,Ndiethyl	18.22	177	271.50492	$C_{16}H_{33}NS$
8	Dihydroapohemanthamine	18.48	188	271.31108	$C_{16}H_{17}NO_3$
9	Ethanol, 2-[6-chloro-4-(4-methyl-1-piperidyl)-1,3,5triazin-2ylamino]	18.92	221	46.069	C_2H_6O
10	14, 17-Octadecadienoic acid, methyl ester	20.3	134	294.4721	$C_{19}H_{34}O_2$
11	16-Octadecenoic acid, methyl ester	21.3	248	296.495	$C_{19}H_{36}O_2$
12	N-Cyclooct-4-enylacetamide	22.63	132	87.122	-
13	1,8-Dimethyl-3,6-diazahomoadamantan-9-ol	24.02	151	224.348	$C_{13}H_{24}N_2O$
14	N-[3-Diethylaminopropyl]-4-oxo-1,2,3,4,5,6,7,8-octohydroquinoline	24.57	173	-	-
15	2-Octadecenoic acid, methyl ester	24.97	254	294.4721	$C_{19}H_{36}O_2$

Conclusion:

The hydrocarbon grouping that is differentiated according to their Standard hydrocarbon retention time (RT) is determined by the GC-MS statement. The analysis identified 15 significant fatty acid components that are present in the biodiesel sample as hydrocarbon chains. Palmitic acid (54.64%), oleic acid (28.38%), and EPA (4.72%) were the three main fatty acids found. The upcoming use of biodiesel limits the use of fossil fuels while also assisting in the reduction of hazardous air pollutants that are released during the burning of conservative fuels, which are referred to as "green fuels" because they reduce air pollution. These studies showed that by adjusting various medium components and environmental factors, it is possible to increase lipid production. Additionally, a study of the precise physiological behavior of dietary patterns, fatty acid compositions, etc., In addition to limiting the use of fossil fuels, the upcoming use of bio-diesel aids in reducing the harmful air pollutants that are released during the burning of conservative fuels, which are therefore referred to as "green fuel."

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SYNTHESIS AND PROPERTIES ELUCIDATION OF $CoFe_2O_4$: INSIGHTS INTO ITS STRUCTURAL, AND MAGNETIC PROPERTIES VIA SOL-GEL AND CO-PRECIPITATION METHODS

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Abstract:

This research delves deep into exploring the creation and analysis of $CoFe_2O_4$ (cobalt ferrite) nanoparticles through two distinct chemical techniques: sol-gel and co-precipitation. These approaches were utilized to generate pure $CoFe_2O_4$ samples and assess their impact on the material's structural, optical, and magnetic attributes in a systematic manner. The structural features of the produced $CoFe_2O_4$ nanoparticles were scrutinized using X-ray diffraction (XRD) and scanning electron microscopy (SEM), uncovering their crystalline structures and particle shapes. Magnetic characteristics were evaluated through vibrating sample magnetometry (VSM), demonstrating the material's potential for applications in magnetic storage and sensor technology. Analysis of XRD data revealed both samples exhibited Fd-3m space group with cubic structure. The typical particle sizes were obtained to be 35.85 and 38.14 nm using Debye-Scherer's equation for the sol-gel and co-precipitation methods, respectively. SEM analysis results showcased non-uniform grain shapes at a microstructural level. Magnetization values at room temperature (RT) were measured at 38.48 and 36.71 emu/g for sol-gel and co-precipitation methods, respectively. These assets make $CoFe_2O_4$ suitable for countless applications including microelectronics, spintronics, optics, optoelectronics, magnetic resonance imaging (MRI), and memory devices. This study offers valuable insights into the relationship between synthesis techniques and the resulting characteristics of $CoFe_2O_4$, providing a comprehensive understanding of how these factors can be customized for specific technological uses.

Keywords: $CoFe_2O_4$ Spinel Ferrite, Optical Properties, Magnetic Properties, Sol-Gel, Co-Precipitation

Introduction:

Nanotechnology explores the world of dimensions smaller than 100 nanometers, focusing on physical, chemical, and biological phenomena at the nanoscale. A nanometer is one-billionth of a meter and serves as a key unit in nanoscience. Nanoparticles come in various shapes and forms, playing a pivotal role in connecting bulk materials with atomic or molecular structures. The study of nanomaterials falls under the umbrella of materials science in nanotechnology, where synthetically produced nanomaterials are commonly known as nanoparticles. These materials exhibit diverse properties based on their size, shape, and surface characteristics, such as electrical, optical, and catalytic properties. The catalytic capabilities of nanomaterials are attributed to their extensive surface area and high surface-to-volume ratio [1-7].

Given the growing applications of nanoparticles, there is a pressing need to categorize these versatile particles systematically. Nano-objects can be grouped into different forms like nanofibers, nanorods, nanocomposite, nanowires, nanoshells, nanospheres, carbon nanotubes, and polymeric nanoparticles. Nanofibers are slender fibres with a diameter of 100 nanometers or less, while nanotubes represent carbon allotropes with a cylindrical nanostructure. Nanorods take on a rod-shaped morphology at the nanoscale, while nanocomposites consist of solid materials with one, two, or three dimensions below 100 nanometers. Structures within nanocomposites have nano-scale repeat distances between phases, contributing to their unique properties [8-15].

Nanoparticles, such as nanowires, nanoshells, and nanospheres, are widely utilized in various fields like medicine, energy, and electronics due to their unique properties. These nanoparticles play a crucial role in cancer treatment, drug delivery, and other applications by offering targeted delivery and reduced toxicity. Core/shell nanoparticles, like dendrimers and quantum dots, bridge the gap between material chemistry and industries such as electronics, biomedicine, and optics, thanks to their stability and versatile applications. Ferrites, among the many synthesized nanoparticles, are particularly common and valuable in a range of technological applications.

Ferrites (MFe_2O_4), with M being Cu, Ni, Co, and more, can be described as magnetic substances made up of oxides with ferric ions as the primary component. These materials are created by blending metal oxides to form a magnetic entity. There are two main categories: hard ferrite and soft ferrite. Soft ferrites can be easily magnetized and demagnetized, making them ideal for storing or transmitting magnetic energy in different wave forms, while hard ferrites are composed of barium, cobalt, or strontium compounds and are commonly used in refrigeration. In comparison to ferromagnetic alloys, ferrites offer benefits such as suitability at higher frequencies, better heat resistance, resistance to corrosion, and lower costs. They showcase fascinating magnetic, electrical, and optical characteristics like high corrosion resistance, electrical resistivity, low eddy currents, moderate saturation magnetization, and a broad range of coercivity. Consequently, ferrites are a fitting choice for various technological purposes. This makes them valuable in applications such as transformers, electric motors, various microwave components, electronics, instrumentation, computers, power conversion, magnetic storage, catalysis, and biotechnology. Among the diverse ferrite types, spinel ferrite nanoparticles have garnered attention due to their promising technological uses, particularly in biomedicine. The groundwork in this area was laid by Hilpert and furthered by Forestier, who initiated chemical studies on the production of various ferrites, marking the beginning of ferrite synthesis as a burgeoning field with ongoing potential for exploration.

Cobalt ferrite ($CoFe_2O_4$) nanoparticles represent a prime illustration of spinel ferrites. They are widely utilized nowadays across various scientific fields: for example, in magneto-optical devices, as a contrast agent in MRI, for drug delivery systems, medical diagnosis, pigments in paints and ceramics, magnetic disc drives, magnetic separation, and magneto hyperthermia. Moreover, the exceptional physical and chemical stability of $CoFe_2O_4$ makes it ideal for magnetic recording applications, such as audio and video-tape, and high-density digital recording disks. $CoFe_2O_4$ stands out as a well-known hard magnetic material with a high Curie temperature (T_C 520 °C), a substantial coercivity (H_c) of 4.3 kOe at room temperature, significant magnetic anisotropy, moderate magnetization (M_s), high permeability, good saturation magnetization without a preferred direction for magnetization, and remarkable electromagnetic performance. Additionally, it is cost-effective and straightforward to prepare, hence widely used in the production of sensors and digital recording disks. Recently, there has been a surge in research on the electrocatalytic activity of $CoFe_2O_4$ nanoparticles for solar thermochemical hydrogen production. Furthermore, it boasts exceptional chemical and physical stability, mechanical hardness, wear resistance, ease of synthesis, and electrical insulation. Additionally, $CoFe_2O_4$ possesses the highest S-L coupling value and anisotropy constant compared to other spinel ferrites. It features an inverse spinel structure with a cubic closed pack arrangement where all Co^{2+} ions occupy octahedral sites while half of the Fe3+ ions share the same location, with the remaining Fe^{3+} ions occupying tetrahedral sites. Size control of spinel ferrite-based nanoparticles can be achieved by regulating physical parameters and chemical conditions during the chemical condensation reaction. The particle size and distribution can be controlled by managing the reaction rate, annealing temperature, and duration. Therefore, it is essential to synthesize $CoFe_2O_4$ and other ferrites using simple and reliable methods [16-30].

There is a wide array of techniques available for synthesizing nanoparticles. Among the commonly accepted methods are combustion, co-precipitation, sol-gel technique, mechanical alloying, wet chemical route, thermal treatment, sonochemical reactions, microwave plasma, host template, microemulsion, chemical vapor deposition, hydrothermal synthesis, pyrolysis, ion implantation, gas condensation, and precipitation, to name a few. While numerous methods exist for nanoparticle synthesis, they can be broadly categorized into two main approaches: Bottom-Up Approach and Top-Down Approach. The Bottom-Up approach involves building up nanoparticles from simpler substances, such as in sedimentation and reduction techniques. On the other hand, the Top-Down Approach is a more recent destructive technique where larger starting materials are broken down, and after several steps, suitable nanoparticles are obtained, for instance through grinding/milling and other decomposition techniques.

Nanoparticles created using sol-gel and co-precipitation methods offer a simpler and cost-effective way to control particle size, enhancing their properties when applied with organic compounds. The use of nanotechnology has led to the development of smaller sensors and components in chip design, resulting in lower power consumption, reduced weight, and lower costs in electronics. The synthesis and application of L-Cyst functionalized magnetite NPs have shown promising results in removing Pb2+ and Cr6+ from water, highlighting the importance of nanoparticles in addressing nanoscale challenges for improving lifestyles [19-30].

Experimental Section:

1. Materials and Reagents

The different chemicals were utilized in their pure form without undergoing additional purification and were of the highest quality. A 0.2 M cobalt nitrate $Co(NO_3)_2.6H_2O$ (Alfa Aesar), 0.4 M Ferric nitrate $Fe(NO_3)_3.9H_2O$ (Alfa Aesar), Citric acid or CA ($C_6H_8O_7$), Sodium hydroxide (NaOH), Distilled water (DW), and Ethanol (C_2H_5OH) were employed.

2. Synthesis of $CoFe_2O_4$ via Sol-Gel Technique

This technique involved dissolving appropriate stoichiometric quantities of 0.2 M $Co(NO_3)_2.6H_2O$, 0.4 M $Fe(NO_3)_3.9H_2O$, and 0.4 M Citric acid ($C_6H_8O_7$) in DW. The ratio was 1:2:2 for $Co(NO_3)_2.6H_2O$: $Fe(NO_3)_3.9H_2O$: ($C_6H_8O_7$). The solution was heated to 80 °C and stirred for 2 hours, resulting in a brown gel. Impurities were removed through calcination at 800 °C. The gel transformed into a fluffy mass upon drying, breaking into flakes. The $CoFe_2O_4$ synthesis through sol-gel method is illustrated in Fig. 1.

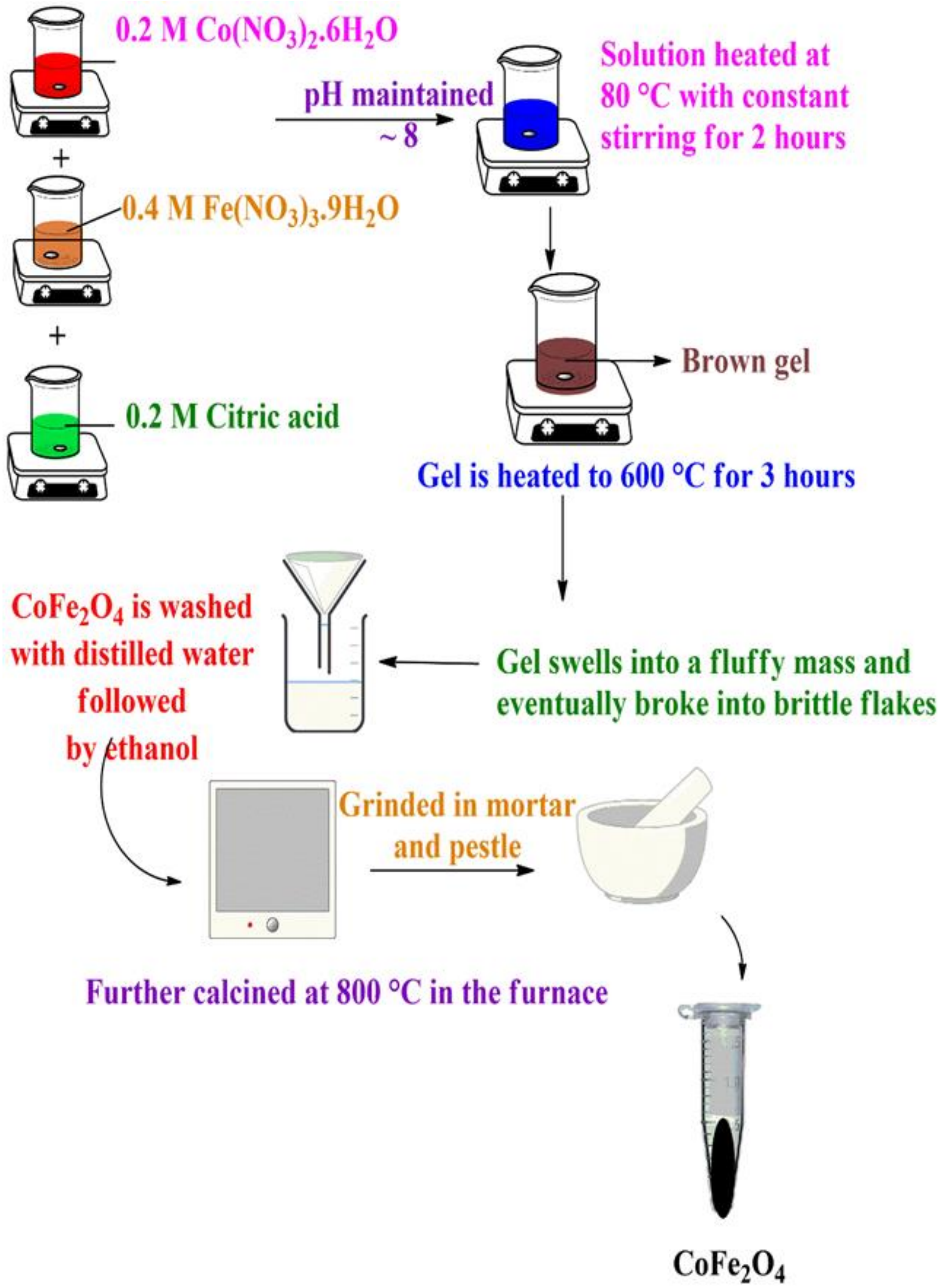

Figure 1: Synthesis of $CoFe_2O_4$ by Sol-Gel Method

3. Synthesis of $CoFe_2O_4$ by Co-Precipitation Method

0.2 M $Co(NO_3)_2.6H_2O$ (2.9104 g) and 0.4 M $Fe(NO_3)_3.9H_2O$ (8.0798g) solutions were heated separately and then combined in a flask. A 5 M NaOH solution was added drop by drop, and the mixture was heated at 150°C for 2 hours. The resulting black $CoFe_2O_4$ was washed, dried, and characterized using various methods as shown in Fig. 2.

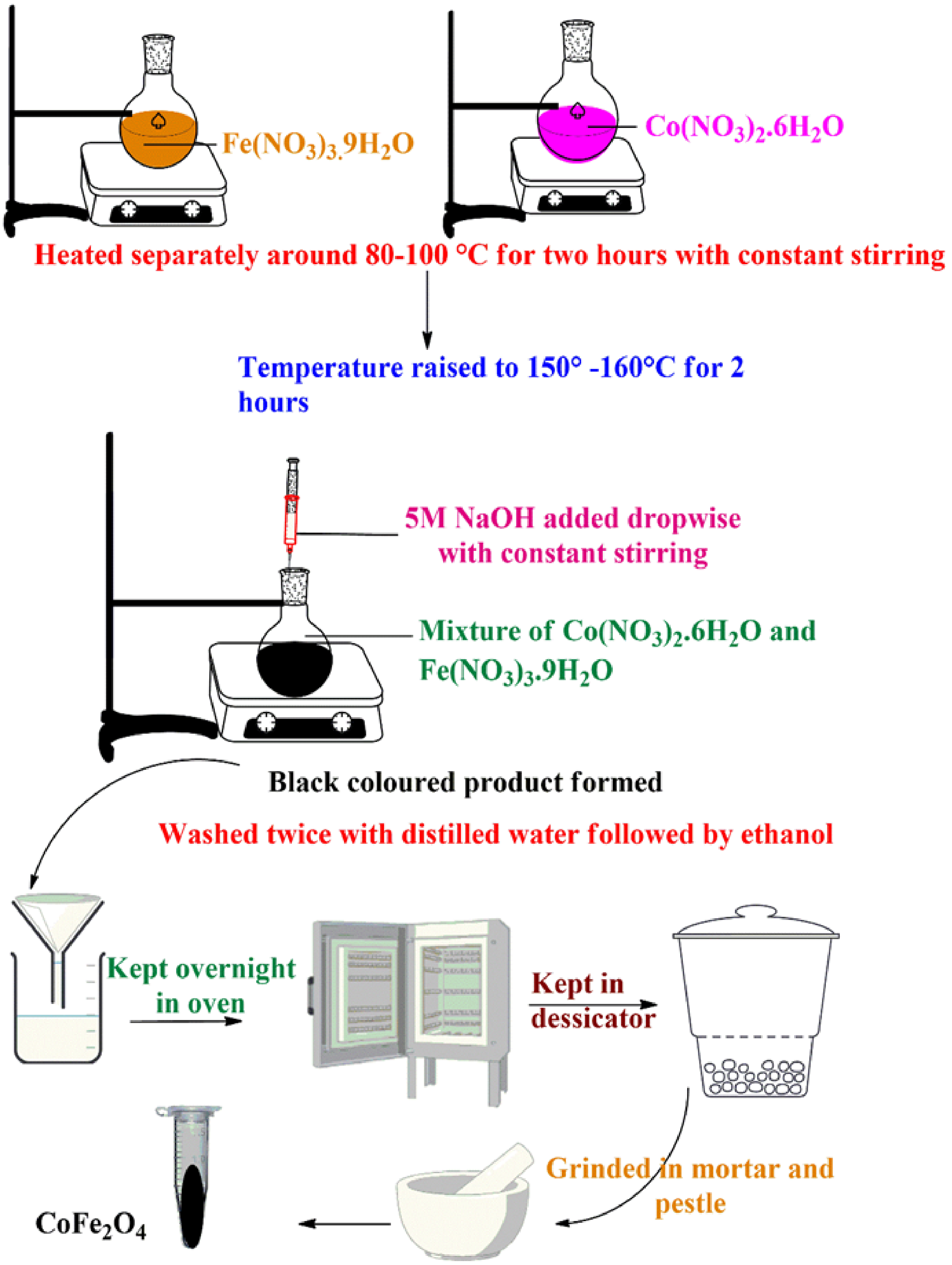

Figure 2: Experimental Setup for Synthesis of $CoFe_2O_4$ by Co-Precipitation Method

4. Characterization Used

X-ray diffraction (XRD) analyzed structural features and phase composition using a Smart lab diffractometer operating at 45kV 40mA with λ = 1.5402Å, while microstructural morphologies were observed through field emission scanning electron microscopy (FESEM), and magnetic properties were assessed using a vibrating sample magnetometer (VSM) at room temperature (RT).

Results and Discussion:

1. XRD Analysis

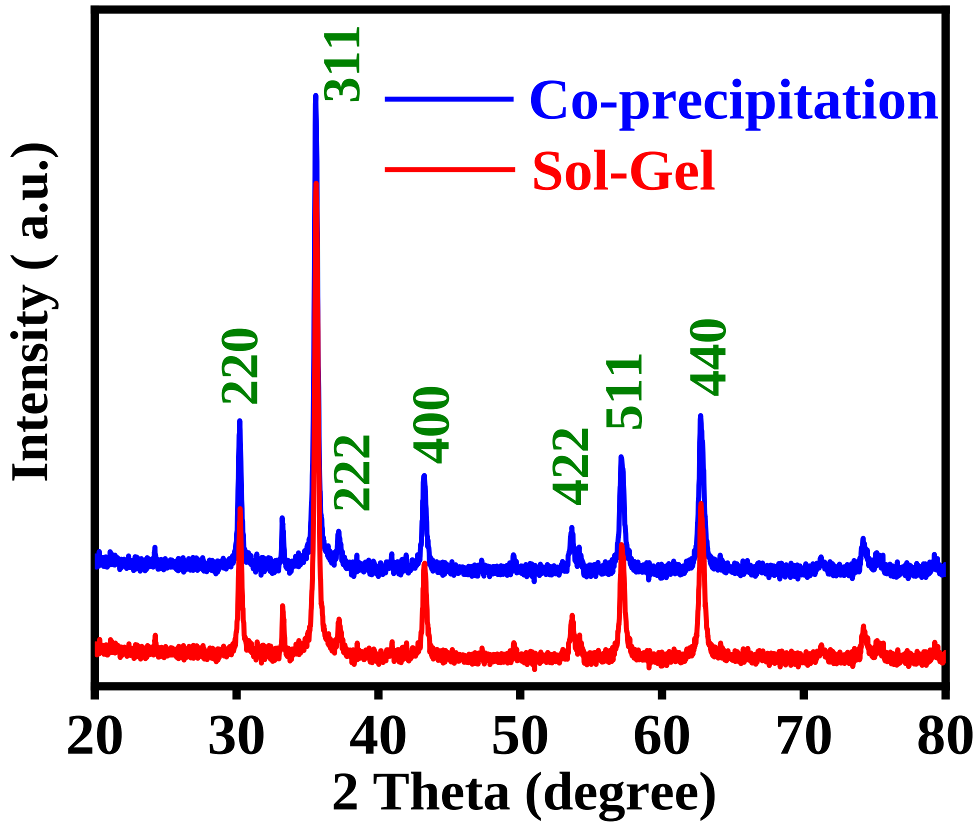

Figure 3: XRD pattern of $CoFe_2O_4$ by Sol-Gel and Co-Precipitation Methods

Fig. 3 illustrates the XRD data for $CoFe_2O_4$ created through the sol-gel and co-precipitation techniques. The data shows a distinct presence of a cubic spinel phase structure with the Fd-3 m space group. The XRD pattern displays well-defined planes corresponding to diffraction angles (2 θ) that align perfectly with JCPDS standard card no. 003-0864. Peaks in the XRD pattern of $CoFe_2O_4$ occur at 2θ = 30.135 (220), 35.495 (311), 37.130 (222), 43.139 (400), 47.233 (331), 53.520 (422), 57.053 (511), 62.652 (440), 65.876 (531), 66.933 (442), 71.081 (620), 74.124 (533) and 75.128 (622), matching the ferrite structure's peak data [24].

The average size was calculated using Scherrer's equation (eq. 1):

$$\tau = \frac{K\lambda}{\beta \cos\theta} \qquad [1]$$

where K is a dimensionless factor (0.94), λ is X-ray wavelength (0.15405 nm), line broadening at FWHM (β), Bragg's angle θ (~ 17.7 for both), and mean line broadening value (τ). By applying Debye-Scherer's equation, the average sizes of $CoFe_2O_4$ were found to be 35.85 and 38.14 nm. Furthermore, there was a strong agreement among the significant peaks of $CoFe_2O_4$ produced by both methods. Fig. 4 shows crystal structure of $CoFe_2O_4$ obtained using VESTA software via (a) sol-gel and (b) co-precipitation methods respectively

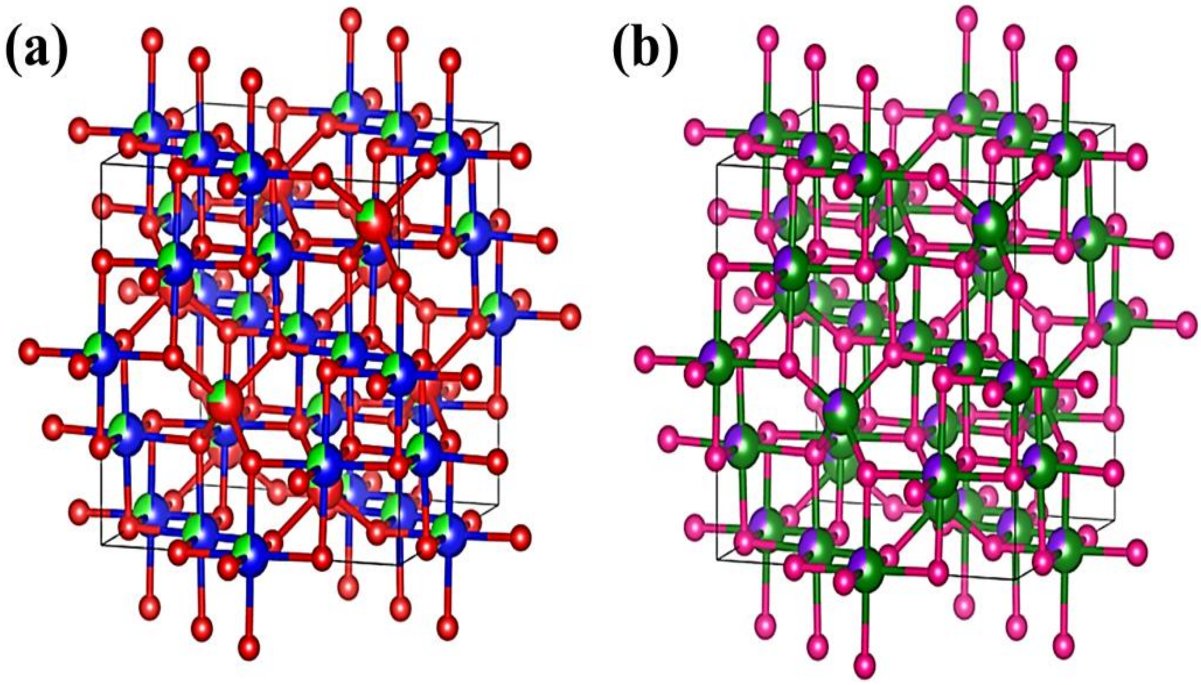

Figure 4: Crystal Structure of $CoFe_2O_4$ obtained using VESTA software via (a) sol-gel and (b) co-precipitation methods respectively

2. Williamson- Hall (WH) Plot

The combination of reduced crystal size (L) and micro-strain caused the XRD peaks to become broader. This means that the L predicted by Scherer's equation is typically slightly smaller and not always precise. To overcome this limitation, Williamson and Hall introduced a W-H plot (eq. 2):

3. $\beta \cos\theta = k\lambda/L + 4\mathcal{E} \sin\theta$ [2]

where L represents crystal size and other symbols have their usual meanings. This equation has been utilized to generate a W-H plot for $CoFe_2O_4$, as shown in Fig. 5 (a) and (b). In the figure, a straight line is visible, with the intercept k/L indicating L and the slope m directly indicating the micro-strain value. The measurements for $CoFe_2O_4$'s L and micro-strain were determined as 52.75 nm and 1.173 x 10^{-3}, respectively for the sol-gel method, while for co-precipitation, these values were 53.95 nm and 2.14 x 10^{-3}, respectively. The L values obtained from eq. 1 are higher than those from Scherer's equation, suggesting the presence of surface flaws and altered crystallinity in the samples [19-25].

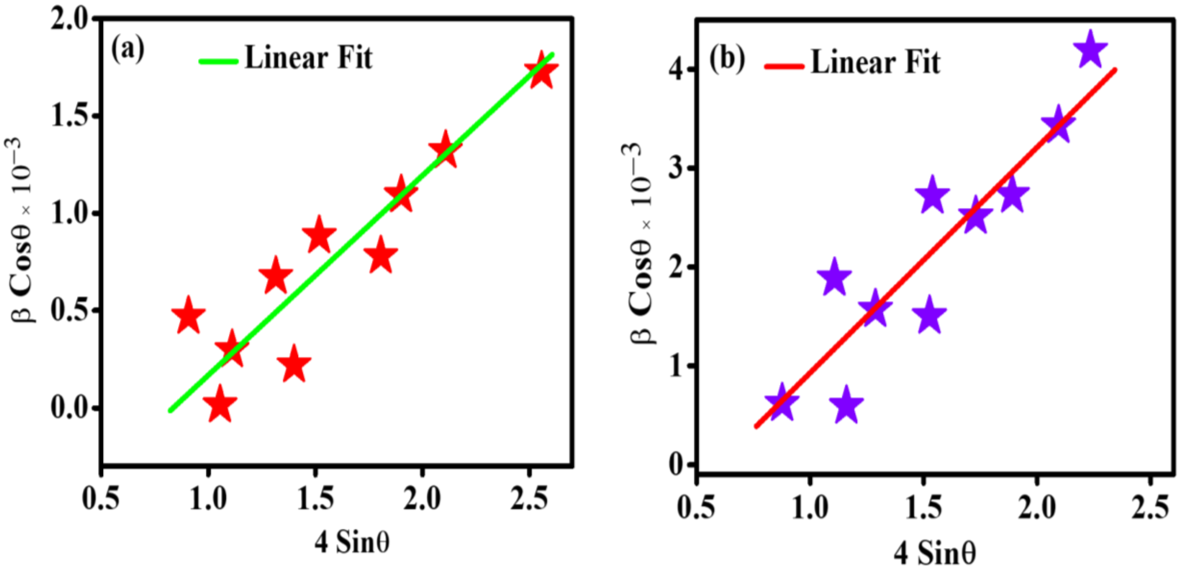

Figure 5: W-H plot of $CoFe_2O_4$ via (a) sol-gel and (b) co-precipitation methods respectively

3. Microstructural Analysis of FESEM data

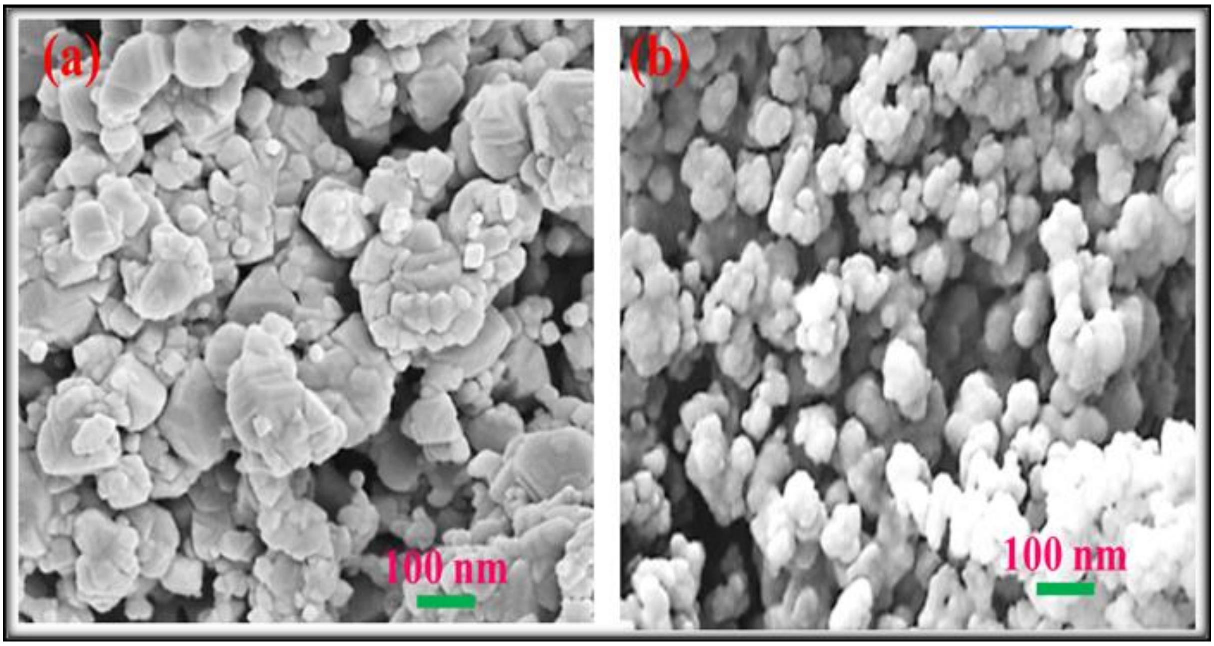

Figure 6: FESEM images of $CoFe_2O_4$ via
(a) sol-gel and (b) co-precipitation methods respectively

The examination of structural features, morphologies, surface properties, particle sizes, and microstructures for both samples of $CoFe_2O_4$ was meticulously studied through the utilization of FESEM images depicted in Figure 6 (a) and (b). The specimens displayed a tendency to clump due to the interplay of various forces like electrostatic, magnetic attraction, and Van der Waal's interactions among NPs. It was noted that the distribution of $CoFe_2O_4$ particles was not uniform, with most particles showcasing irregular shapes such as triangular, spherical, and cylindrical. The grain size in the case of the sol-gel method was notably smaller than that of the co-precipitation method, as observed visually and corroborated by the histogram curves; potentially attributed to a higher propensity to clump [24]. Morphological analysis unveiled the existence of small voids owing to sample porosity or void fraction, as well as agglomeration in the produced materials. Porosity calculations using ImageJ software revealed values of 11.38% and 15.37%, respectively. The Gaussian distribution depicted in the frequency distribution histogram curve of both $CoFe_2O_4$ samples, as displayed in Fig. 7 generated using ImageJ software, showcased similarities. Figure 7 (a) showcased the histogram distribution for $CoFe_2O_4$ particles (sol-gel) with sizes ranging from 10 to 70 nm and average size of approximately 40 nm. Fig. 7 (b) illustrates the histogram curve for $CoFe_2O_4$ particles (co-precipitation) with sizes varying between 20 to 80 nm and an average size of around 45 nm. Consequently, the grain size of $CoFe_2O_4$ particles (sol-gel) was smaller than that of $CoFe_2O_4$ particles (co-precipitation). Comparable results were also obtained from the analysis of crystal structure, indicating that size of sol-gel case was smaller in comparison to co-precipitation one.

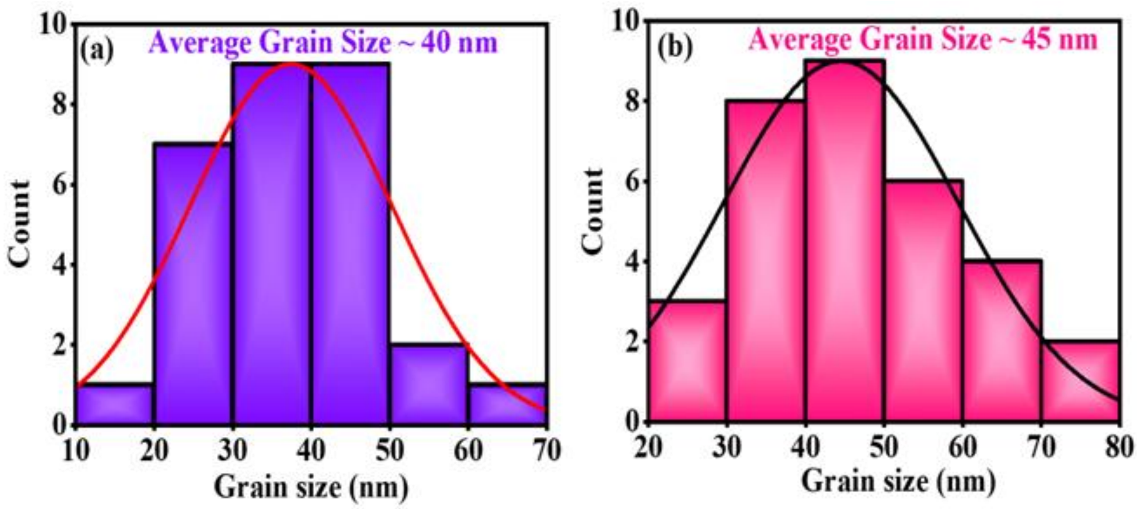

Figure 7: Histogram for average grain size for $CoFe_2O_4$ via (a) sol-gel and (b) co-precipitation methods respectively

4. Magnetic Measurement

The magnetic properties of $CoFe_2O_4$ samples in powdered state were explored using a vibrating sample magnetometer (VSM) at 2 T, depicted in Fig. 8. The magnetic hysteresis loop ranged from -20,000 Oe to 20,000 Oe. For sol-gel and co-precipitation methods, $CoFe_2O_4$ displayed MS values of 38.48 and 36.71 emu/g, respectively, indicating a decrease in magnetization with the co-precipitation method. The magnetic characteristics stem from the interplay between two antiparallel sublattices linked by robust super-exchange interactions via O^{2-} ions, resulting in a ferrimagnetic behaviour as shown in figure [23-25]. $CoFe_2O_4$ exhibits a ferrimagnetic nature, akin to ferromagnetic materials, with magnetic moments of iron and cobalt ions not entirely aligned, but partially cancelling out to yield a net magnetization. Within the spinel structure, $CoFe_2O_4$ hosts cations in two types of sites: tetrahedral (A) and octahedral (B). Cobalt ions predominantly occupy B sites, while iron ions are spread across A and B sites, shaping the observed magnetic behaviour. The magnetic attributes of NPs are significantly impacted by their size and structure, influencing values of M_S, M_R, and H_c. The magnetic anisotropy in $CoFe_2O_4$ arises from partial quenching of Co^{2+} ions' orbital angular momentum. Fluctuations in MS are linked to cationic movement changes, particularly the swapping of Co^{2+} and Fe^{3+} ions between O_h and T_d sites [24]. Table 1 shows crystal structure parameters, calculated values of average crystalline size and magnetization values of $CoFe_2O_4$ respectively via sol-gel and co-precipitation methods respectively.

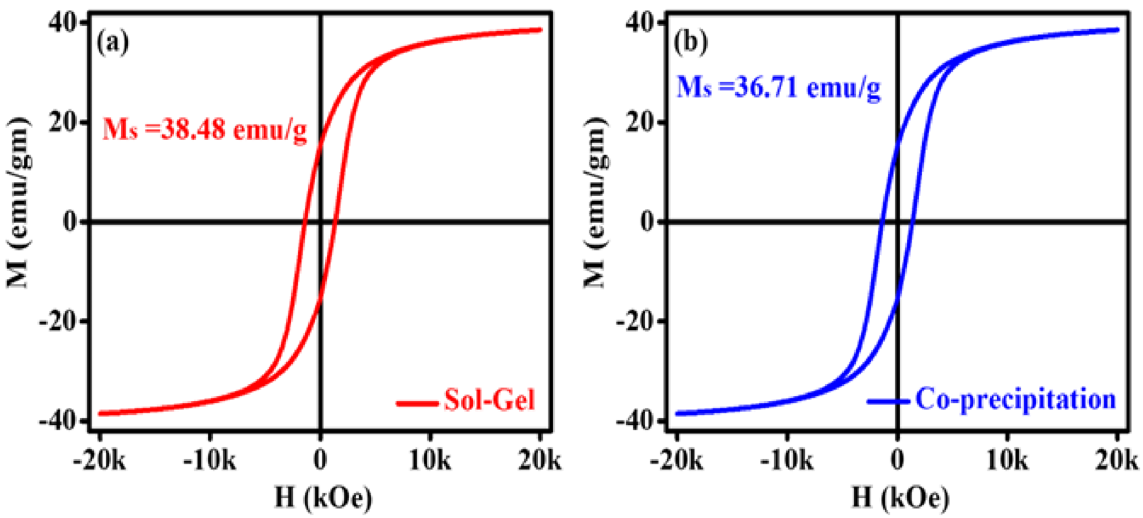

Figure 8: M-H loop of $CoFe_2O_4$ at RT via
(a) sol-gel and (b) co-precipitation methods respectively

Table 1: Structural parameters of $CoFe_2O_4$ via sol-gel and co-precipitation methods

Sample	Crystallite size (nm) By Scherer's Eq.	Crystalline size (nm) By WH Eq.	Strain (x 10^{-3})	Grain Size (nm)	Magnetization Ms (emu/g)
$CoFe_2O_4$ (Sol-gel)	35.85	52.75	1.173	40	38.48
$CoFe_2O_4$ (Co-precipitation)	38.14	53.95	2.14	45	36.71

Conclusion:

The techniques of sol-gel and co-precipitation were effectively utilized in the production of $CoFe_2O_4$. These samples exhibit a cubic configuration with the Fd-3m space group, as indicated by XRD analysis. At room temperature, the magnetization levels of $CoFe_2O_4$ were measured at 38.48 and 36.71 emu/g through the sol-gel and co-precipitation processes, respectively. Through various studies and characteristics, it is evident that $CoFe_2O_4$ holds promise as a material suitable for applications in microelectronics, optoelectronics, magnetoelectric sensors, and spintronic devices.

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PHASE SENSITIVE X-RAY IMAGING

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Introduction:

The importance of X-ray radiography has been recognized since the discovery of X-ray in 1895. In 1901 Roentgen received the first Nobel Prize in Physics for the discovery of X-ray. X-ray radiography plays a central role in many diverse areas such as industrial inspections, medicine, materials science, chemistry, quality control, astronomy, forensic science, security and bio-medical imaging. Examples of X-ray radiography include: X-ray radiography for detecting failures in materials such as cracks, porosities and welding imperfections, X-ray screening of baggage, mammography for tumor or cancer detection, X-ray radiology for medical diagnostic purposes. Due to the high penetrating power of X-rays, this technique is used as a non-destructive imaging technique. X-ray radiography can produce images of the internal structure of an object, without damaging the object [1]. Since Roentgen's discovery of X-rays, almost all X-ray radiographs have been obtained and interpreted on the basis of absorption contrast, involving the imaginary term (β) of the X-ray refractive index $n = 1 - \delta - i\beta$ [2, 3]. In this approach, a film or other detector is placed directly in contact with the sample, where the geometric shadow of highly absorbing parts of object produces intensity contrast. The contrast in conventional absorption-based X-ray imaging techniques depends upon the object thickness and its atomic number. Hence the contrast of the absorption-based X-ray images decreases when either atomic number of the object or object thickness decreases. The conventional absorption X-ray imaging is able to distinguish between hard (high Z) and soft (low Z) materials but it fails to image soft materials like polymers, carbon-fiber composites and soft tissues as the absorption is very less for such materials [4]. In fact, this is one of the major drawbacks of the conventional absorption-based X-ray imaging techniques for medical or biological imaging. Conventional absorption radiography is not an ideal imaging technique as it is based on the X-ray dose deposition and so can require long exposures and a relatively high X-ray dose to get good contrast. This is generally undesirable, as it may involve significant risks for a patient.

In the last few years, a new imaging technique named Phase Contrast Imaging is being developed to remove the limitations of X-ray imaging and it promises to revolutionize the way soft material imaging has been conducted till now. The contrast produced in X-ray phase contrast imaging, depends on differences in the real part (δ) of the refractive index. The real part of refractive index is nearly 1000 times greater than absorption contrast at 10 - 100 keV range [5] for materials. This leads to better sensitivity and contrast than the conventional absorption X-ray imaging. Hence the objects that have very less absorption for X-ray can also be studied using the contrast produced due to the real part of the refractive index (phase) alone. Such a technique is also well suited to imaging features where there is a sudden change in material density and/or material thickness across the X-ray beam, such as for edges and material discontinuities [6].

Phase contrast imaging has recently been the subject of considerable worldwide research, using both laboratory sources and synchrotrons [7-11]. Phase contrast imaging using a synchrotron has shown that refraction induced X-ray contrast is a very valuable analytical tool, allowing phase to be measured [12, 13], and allowing phase tomographic images to be acquired [5, 14-16]. In laboratory-based sources, Wilkins and co workers [2, 4] showed that refraction can significantly augment the image contrast. Using an ultrafast laser-based system where hard X-rays can be produced much more cheaply than with a synchrotron, Toth and Kieffer [17] showed that phase contrast imaging produced edge enhancement and revealed details that are difficult to observe or even undetectable in absorption images. For several applications, thermal neutron phase radiography [18, 19] has also been developed. In such cases, phase contrast effects can enable the enhanced detection for cracks or edges in metal samples which are otherwise opaque to X-ray.

Methods of Phase-Sensitive Imaging

The contrast in conventional absorption-based X-ray imaging techniques depends upon the object thickness and its atomic number. Hence, the contrast of the absorption-based X-ray images decreases when either atomic number of the object or object thickness decreases. In fact, this is one of the major drawbacks of the conventional absorption-based X-ray imaging techniques. However recent investigations [4, 8] have proved that the contrast in the imaging process can be improved by using coherent X-ray sources. This implies that both the amplitude as well as phase information can be utilized thereby improving the contrast in the imaging process. These new methods are based on the fact that just like any other wave, propagation of X-rays through any material medium introduces a change of phase across X-ray wavefront. This change of phase across the wavefront depends upon the spatial frequency of the feature, electron density of the material etc. Hence, the phase variation across the wavefront carries detailed information about the different features of the object. These phase gradients in the wavefront can be made to manifest themselves as redistribution of X-ray intensity in the imaging plane using suitable techniques. This results in contrast enhancement across the edges or boundaries for weakly absorbing materials. As the contrast does not directly depend upon the energy deposited in the object, the dose delivered to the sample can be reduced. In this sense, this new imaging technique can be truly considered as non-destructive imaging techniques. Phase contrast imaging is one of the techniques of a class of such phase sensitive technique. These new imaging modalities are collectively called Phase-Sensitive Imaging Techniques.

They have been implemented in following three major different modes for phase imaging worldwide are:

i. Interferometric Technique (X-ray interferometry)
ii. Diffraction - enhanced imaging (DEI)
iii. Phase - contrast imaging (PCI)

The X-ray interferometry is similar to optical interferometry where the incident X-ray split into two components and X-ray images are formed due to path difference induced by object in one of the components. It depends on phase (ϕ) directly. The method has stringent requirement on spatial and temporal coherence. The second technique of diffraction-enhanced imaging is based on interference of refracted and diffracted waves which are then combined using an analyzer crystal. The image contrast is based on phase gradients ($\nabla\phi$). This also requires both spatial and temporal coherence. The third technique of phase-contrast imaging is based on interference of diffracted and undiffracted waves at some distance behind the sample which are then recorded using detector. The image contrast depends on Laplacian of phase ($\nabla^2\phi$) directly. This technique uses the variations in X-ray refractive indexes of the different substances within the object. Segments of X-ray wavefront is diffracted to a different degree depending on small variations in refractive index of different materials. This requires high spatial coherence of X-ray source. The requirement of temporal coherence for this technique is somewhat less stringent and hence imaging can be done by using polychromatic X-rays as well.

The phase contrast has been exploited in the visible regions long ago. However, lack of availability of highly coherent X-ray source, was a major hurdle for implementing this technique in the X-ray region. Synchrotron sources provided both spatial & temporal coherence and therefore they are the source of choice for implementation of these techniques [3, 20]. However, the use of these facilities is not only expensive but also not suited for day-to-day experimentation. With the availability of microfocus X-ray sources which are point like and can be considered to be spatial coherence (focal spot <10μm), we can also implement in-line phase contrast technique on a laboratory scale. This technique has potential applications in medical field as in early detection of tumor, animal studies and also in material science field as in the study of carbon composite materials, study of polymer-based materials and so forth. Hence this technique can have great potential in the study of new class of materials belonging to industrial and medical science field.

The Interferometric Technique

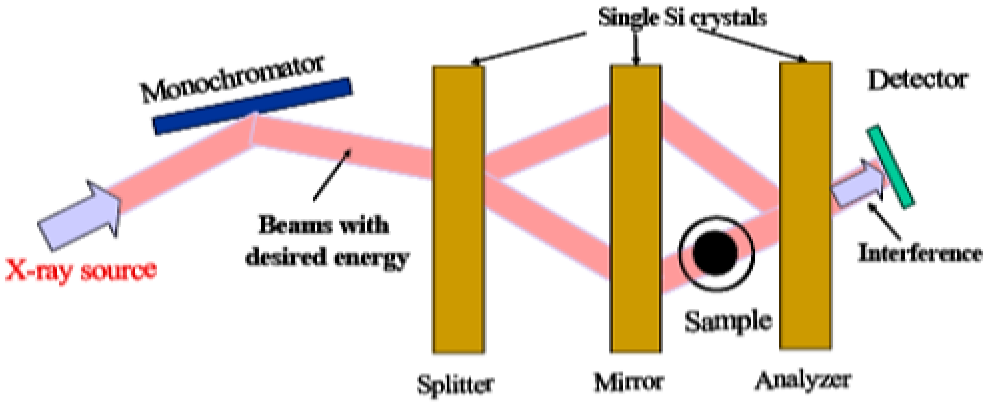

Figure1: An X-ray interferometer phase imaging using monochromatic synchrotron radiation [22]

Interferometry is based on interference of direct beam and beams which passes through the sample. The resulting interference fringes can be used to deduce the relative phases of the two waves. This requires perfect alignment and coherence. This is a quantitative phase measurement technique. There are many different types of interferometry [21], but all of them follow the same basic principle.

In this case any phase differences in the optical path for the beam transmitted through a sample are directly encoded using a monochromatic beam. The first crystal splits the incident X-ray beam into two after it has been filtered by a monochromator. In a symmetrical experimental scheme, the intensity of both beams is equal to each other. Beam splitting can be done in two ways: wavefront splitting and amplitude splitting [23]. Young's double slits, Fresnel's bimirrors and prisms are example of X-ray wavefront splitters [23].

Amplitude splitting is superior in some applications because in amplitude splitting case, high spatial coherence is not as essential as in the case of wavefront splitting [11]. Crystals are used for amplitude splitting in the hard X-ray region and free-standing multilayers or gratings are used for amplitude splitting in the soft X-ray region. The middle crystal acts as a mirror, sending the beams back toward each other. The beams meet at the third crystal (analyzer crystal) which recombines them. This is placed at the region of intersection of the two beams. A sample placed in the path of one of the beams between the mirror and analyzer, will introduce a phase shift and distort its wavefront. The interference fringes are then recorded using a detector in the path of the outgoing beam.

The construction of X-ray interferometers is in general more complex than the construction of optical interferometers. X-ray wavelengths are three orders of magnitude shorter than visible light and consequently an X-ray interferometer requires much tighter alignment and greater mechanical stability than for visible light interferometers. When the optical path difference fluctuates by more than a wavelength, the corresponding fringe pattern can be significantly changed. If the time required to record the fringes is longer than the time constant of fluctuations in the system, fringe contrast is lost [11].

X-ray interferometry was first demonstrated by Bonse and Hart [24] and Ando *et al.* [25] first recorded X-ray phase images using a configuration as shown in Figure 1.2 for imaging of bone tissues and of a slice of granite. Momose *et al.* [11, 26, 27] developed this direct phase shift measurement technique into computed tomography. Each measurement allows one to obtain the map of the phase shift which is proportional to an integral over the path of X-ray beam on the decrement of the real part of the refractive index. So this map may be considered as a projection of the real part of the refractive index of the object along the path of X-ray beam. In computed tomography, one can obtain a set of such projections by rotating the object. Then the standard technique of computed tomography allows the reconstruction the distribution of the electron density, which is related to the real part of the refractive index inside the object.

There are several applications of X-ray interferometry including measurements of optical constants [24], measurements of strains [29] and lattice distortions in crystals [29], and measurements of dispersion surfaces [24]. The technique is generally limited by difficulties in ensuring the coherence of the X-rays, the coherent division of the X-ray beam, the stability of the optical path length and the limited availability of high-quality optics.

However, despite these difficulties many of these applications are still pursued, and are now being applied at synchrotron radiation sources around the world [27, 11].

Diffraction - Enhanced Imaging

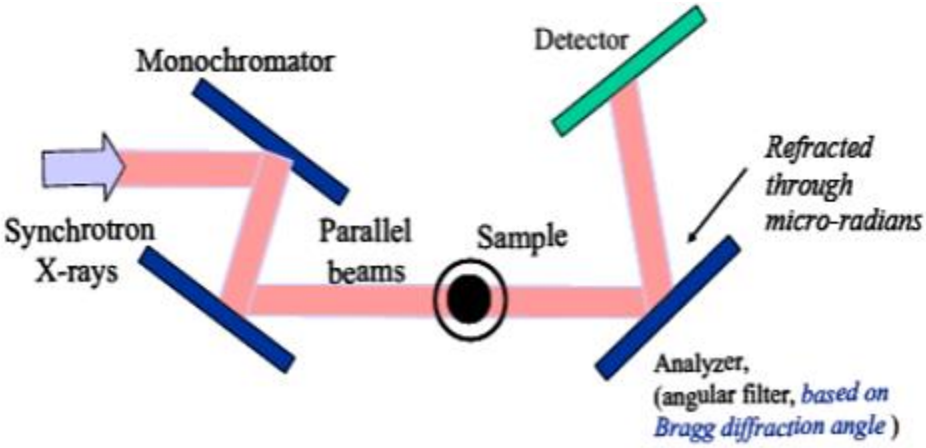

Figure 2: Diffraction enhanced X-ray imaging using monochromatic synchrotron radiation [22]

Diffraction-enhanced imaging (DEI) is a phase-sensitive X-ray imaging technique based on the use of an analyzer placed between the sample and the detector. It is a differential method that relies on the phase difference across the wave front [30]. The phase gradient can be resolved with a crystal analyzer that is placed between the sample and the detector. When aligned with the monochromator crystal, the analyzer rejects all scattered X-rays which blur the image. A slight misalignment (~ micro-radian) between the monochromator and analyzer transforms the rays refracted at different angles (due to gradient in phase shift) into different shades of gray on the detector. In this way the phase variations introduced by the internal structure of the sample is converted into image contrast.

DEI is particularly sensitive to the boundaries of the details, where strong refraction effects take place. Thus, an edge-enhancement effect is perceived even from non-absorbing or weakly absorbing objects and details not detectable with conventional techniques are clearly visible.

In DEI, the outgoing beam is intercepted by an analyzer, placed between the sample and the detector, which acts as an angular band-pass filter of extraordinary sensitivity. And only those X-rays which satisfy the Bragg condition for the analyzer will be diffracted into the detector. In practice, the analyzer is obtained by using one (or more) crystals (as a silicon), similar to those of the monochromator. Since the crystal has a reflectivity characteristic, known as rocking curve, which varies very strongly with angle over a few micro radians, the slope of that curve effectively converts the X-ray phase shifts and resulting angular changes into intensity variations. The angular band acceptance of the filter is determined by the width of the rocking curve, i.e. the intensity curve that is obtained by rocking the analyzer crystal around the Bragg angle with no sample in the beam. The rocking curve full-width at half-maximum (FWHM) is typically in the order of 1–100 μrad, and thus comparable with the tiny deviation produced in the sample.

As demonstrated in [31], this allows to record angular deviations that occur in the sample as intensity modulations on the detector. Thus, refraction and ultra-small angle scattering (absolutely imperceptible in conventional X-ray imaging) are exploited and provide additional contrast besides the conventional X-ray absorption.

Moreover, by setting the analyzer at different positions on the rocking curve, different images are obtained. Particularly meaningful positions are the peak and the half-slopes of the rocking curve. The image acquired at the peak highlights the so-called extinction contrast (which is due to the rejection of small and ultra-small angle scattering), while the images acquired on the slopes maximize the contrast due to refraction. Finally, by combining the two half-slope images according to simple equations, two new images are produced, called apparent absorption image containing information about the absorption and extinction processes, and refraction image including diffraction effects produced by the sample. The former is similar to the conventional absorption image, but it also emphasizes the extinction contrast (scattered X-rays are effectively removed from the image). The latter looks quite different from conventional radiographs since it is entirely due to refraction, and actually represents a map of the refraction angle at each point in the object plane [31].

The setup shown is simplified but in general the information that can be extracted is limited and rather qualitative. This is because the crystal analyzer does not reveal the local phase shift but instead reveals the local phase gradient. However, many groups show maps of the phase gradients [33, 4 and 30] and techniques do exist to produce reconstructed phase maps based on such measurement [34].

This technique is very useful in medical and biological studies particularly for detection of different kinds of biological tissues [4], and a breast tissue sample from humans in phase mammography [35]. In other work, Ingal and Baliaevskaya [33] used the Laue case of diffraction in a crystal analyzer. This allows them to register simultaneously two kinds of detection: in the transmitted beam by using a CCD camera and in the reflected beam by using scintillation counter. This allows the simultaneous observation of the angular position in the rocking curve and the corresponding image contrast. One outstanding result of this method is an image of an aquarium fish [33].

Phase Contrast Imaging

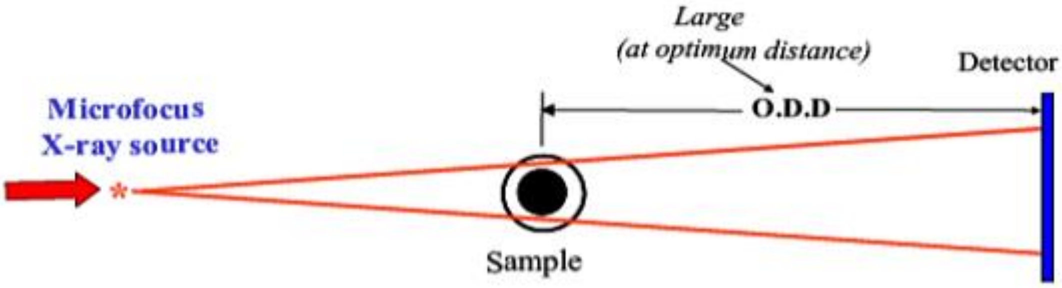

Figure 3: Phase-contrast imaging using a fine source with special coherence [22]

The phase-contrast imaging is based on interference of distorted and undistorted waves at some distance behind the sample which are then recorded using detector. Phase contrast imaging relies on Fresnel diffraction in free space of the wave field exiting the sample. It simply allows the wave field to propagate a sufficient distance away from the sample so that diffraction fringes can be observed. It is a unique contrast mechanism in comparison with other phase sensitive imaging techniques in that it has the advantage of a very simple experimental set-up requiring no optical element. The absence of optical elements implies that the method is intrinsically free from the usual aberrations. This is also known as in-line phase contrast imaging. The phase contrast imaging method allows diffraction effects to be visualized and provides information about the distribution of the real part of complex refractive index in the sample.

Furthermore, for sources with sufficient spatial coherence, this phase contrast based imaging can provide excellent contrast for imaging at micrometer and sub-micrometer scales. In contrast to the other methods which are based on the coherence properties of X-ray beams from a highly sophisticated third-generation synchrotron source, this method is extremely simple and involves almost no instrumentation. The set-up is identical to that of conventional attenuation radiography except in the sample-detector distance. It corresponds to Gabor in-line holography in classical optics and to the defocusing mode in electron microscopy.

In this technique, the X-rays emerging from the sample will propagate through space until they reach the detector. The inhomogeneous phase shifts produced by the sample diffract the X-rays. After some propagation distance, the density of X-rays becomes inhomogeneous leading to observable changes in the intensity distribution. The focus of the thesis is on PCI with microfocus and hence a more detailed discussion is given on PCI.

This simple scheme of phase contrast imaging is routinely realized today on third generation synchrotron radiation sources. Snigirev [8] first explored this technique for micro imaging of organic samples (fibers) using the ESRF source. However, this technique has also generated a considerable amount of interest in the development of more conventional laboratory-based X-ray tube sources which do not demand large distances in the experimental setup. It has been shown that temporal coherence is not a requirement for PCI [36, 37]. Instead, a polychromatic source with a degree of spatial coherence can be utilized. Wilkins *et al.* [5, 8, and 37] developed this technique using a micro or nano focus laboratory X-ray source to get phase contrast images using spherical wave illumination of the object. The wavefront is inevitably distorted by its passage through the object, and this distortion after further propagation manifests itself as an observable intensity change.

McMahon *et al.* [19] and Allman *et al.* [18] demonstrated phase visualization using neutron sources for crack detection in metal samples. Their phase contrast images of a metal sinker and a damaged aeroplane engine turbine blade show an increase in contrast. Toth and Kieffer [17] showed phase contrast imaging of this technique using an ultrafast laser-based hard X-ray source. Projection X-ray radiography of this form was also discussed by Pogany [38] using a contrast transfer function (CTF) formalism. The methods described there give insight into the nature of the image formation under the Fresnel approximation. Cloetens *et al.* [39] used this technique to image a cracked silicon single crystal and metal matrix composite, both in projection and in computed tomography. Using electron microscopy methods, quantitative X-ray phase imaging has been developed [40, 41], for high-brightness sources. The free space propagation technique has also been applied to a very broad range of areas [18, 17; 42, 43].

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ARTIFICIAL INTELLIGENCE IN MATERIAL SCIENCE: REVOLUTIONIZING CONSTRUCTION

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Abstract:

Materials science is the cornerstone for technological development of the modern world that has been largely shaped by the advances in fabrication of semiconductor materials and devices. However, the Moore's Law is expected to stop by 2025 due to reaching the limits of traditional transistor scaling. However, the classical approach has shown to be unable to keep up with the needs of materials manufacturing, requiring more than 20 years to move a material from discovery to market. To adapt materials fabrication to the needs of the 21st century, it is necessary to develop methods for much faster processing of experimental data and connecting the results to theory, with feedback flow in both directions. However, state-of-the-art analysis remains selective and manual, prone to human error and unable to handle large quantities of data generated by modern equipment. Recent advances in scanning transmission electron and scanning tunnelling microscopy have allowed imaging and manipulation of materials on the atomic level, and these capabilities require development of automated, robust, reproducible methods.

Artificial intelligence and machine learning have dealt with similar issues in applications to image and speech recognition, autonomous vehicles, and other projects that are beginning to change the world around us. However, materials science faces significant challenges preventing direct application of the models without taking physical constraints and domain expertise into account. Atomic resolution imaging can generate data that can lead to better understanding of materials and their properties through using artificial intelligence methods. Machine learning, in particular combinations of deep learning and probabilistic modelling, can learn to recognize physical features in imaging, making this process

automated and speeding up characterization. By incorporating the knowledge from theory and simulations with such frameworks, it is possible to create the foundation for the automated atomic scale manufacturing.

Introduction:

Modern civilization is highly dependent on the development of technology. In 2017, about 9.2% of the US economy came from the technology industry, and it also employed more than 11 million people (Cyberstates, 2018). Global R&D spending grew from 1.956% of world GDP in 2007 to 2.228% in 2015 (Basu *et al.,* 2001). The global battery market is expected to grow to $100 billion by 2025 (Mathuros, 2017). Economic studies show that changes in technology are the only source of sustained productivity growth (Basu *et al.,* 2001). The explosive speed of technological development has been driven mainly by advances in the growth, theory, and production of semiconductors and devices, allowing them to penetrate everyday life and make calculations that would have been impossible. The pace of technological change followed what is known as Moore's Law, named after Gordon E. Moore, who speculated in 1965 that component cost complexity would double every year until 1975 and every two years thereafter (Moore, 1998). However, this is expected to end by 2025 when the physical limits of traditional transistor scaling are reached (Waldrop, 2016). Intel has already doubled in almost two and a half years (Clark, 2015). This requires finding unconventional ways to sustain technological growth. One possibility is to scale the design and manufacture of materials and devices to the atomic level (Fuechsle *et al.* 2012). Another promising research direction was the use of complex functional materials such as ferroelectric relaxors and morphotropic systems (Vugmeister, 2006, Woodward *et al.,* 2005), multiferrotics (Fiebig, 2005), spin and cluster glasses (Binder and Young, 1986), nanoscale phase-separated oxides (Dagotto, 2005; Dagotto *et al.,* 2001).

However, the classic synthesis-characterization-theory approach has not proven to keep pace with the needs of materials production, and it takes 20 years or more from discovery to market (Jain *et al.,* 2013; Holdren, 2011). The relationship between the structure of the materials and the desired functionalities (room temperature superconductivity, giant electromechanical or magneto-electric couplings (Spaldin and Fiebig, 2005), efficient room temperature oxygen reduction reactions (Adler, 2004) is not well understood, so the synthetic routes of such materials are not obvious. Unfortunately, much of the existing literature lacks either information about the synthetic conditions or subsequent characterization (Young *et al.,* 2018). Recognizing the aforementioned gaps, a major effort called the Materials Genome Initiative was launched to improve the efficiency of materials discovery and design. This multi-agency initiative was created to bring about a cultural change in materials technology, connect experiment, computation and theory, and promote digital knowledge between universities, government and industry (MGI, 2016). One of the most important achievements of this approach was the development of high-throughput screening of candidate materials for experimental studies (Curtarolo *et al.,* 2013). However, many interesting properties have been defined at scales beyond what can be achieved by first-base simulations with current computer capabilities, or occur in materials whose structure is poorly understood theoretically. An additional difficulty with theory-based approaches is dealing with gaps and understanding dynamic states of matter. These limitations require a closer coupling of experiment and theory. To address this need, my research used the synergy of imaging, simulations, and artificial intelligence (AI) to gain a better understanding of nanoscale materials and pave the way to automated atomic-scale manufacturing.

Artificial Intelligence: The Architect of Tomorrow's Materials

A revolution in architecture and construction is about to take place with artificial intelligence integration. The ability to design building designs and styles, while ensuring compliance with construction legislation, will be one of the most exciting uses of artificial intelligence in this area. This technology will allow architects and engineers to work more effectively, with a view to creating buildings which are more energy efficient as well as flexible for the user.

A large amount of data in the field of building design, construction materials and codes can be analysed by artificial intelligence algorithms. AI can help architects and engineers to optimise building design and functionality through analysis of these data. In order to allow architects to focus on more creative aspects of the design process, AI can generate designs that are both aesthetically pleasing and functional. The creation of floor plans is one use case for AI in the design of a building layout. AI will be able to generate floor plans that maximise the utilisation of space while maintaining its operation and meeting user needs, by analysing data on how people are using their spaces. The AI can also analyse building regulations with a view to ensuring that the buildings are fit for purpose and provide reports on compliance issues which need to be dealt with.

The building regulations are an intricate and evolving set of rules. Keeping up with the latest regulations can be a challenge for architects and engineers, which could lead to costly delays in construction projects if they do not comply. By analysing building codes and regulations, as well as providing real time feedback on compliance issues, AI will help to simplify the process of complying with regulatory requirements. In order to comply with building codes and regulations, AI algorithms will also analyse construction drawings and specifications. This can help architects and engineers to find out early in the design process what might be a problem, enabling them to make necessary changes before construction is started. The way buildings are planned and built will be transformed by the use of artificial intelligence in architecture and building. In the field of architecture and construction, we can expect to see even more exciting uses of AI technology as it continues to evolve.

History of Artificial Intelligence

Creating creatures capable of reasoning and performing tasks has fascinated mankind since ancient times. According to ancient Greek mythology, Hephaestus and Daedalus forged animated metal statues of humans and animals that could think. Early Judaism refers to golems, artificial creatures created from mud that can serve humans. Today, the word "robot" was coined by Karel Capek to mean intelligent machines in 1920, and the concept has been a constant theme in fiction ever since (McCorduck, 2009). Alan Turing was the first scientist to claim that a machine can understand logic and perform tasks, which led to the idea of the Turing test, which aims to4distinguish machine intelligence from human intelligence. Artificial intelligence research began enthusiastically in 1956, but results fell short of early promise, leading to major research setbacks in the 1970s and 1990s. Due to increasing computing power and data collection, the field of artificial intelligence re-emerged in the early 2000s, leading first to data mining and machine learning algorithms, and finally, since 2012, to the explosion of deep learning methods. In 2017, a study by the MIT Sloan School found that 23% of companies have adopted AI technology and 23% are in pilot projects (Lorica, 2017).

Artificial Intelligence is one of the hottest words in technology right now, and for good reason. In recent years, many innovations and advances that used to be the sole domain of science fiction have slowly become reality. Experts see artificial intelligence as a production factor that has the potential to bring new sources of growth and change the way work is done across industries. For example, this PWC article predicts that AI could contribute $15.7 trillion to the global economy by 2035. China and the United States will benefit the most from the coming AI boom, accounting for nearly 70 percent of global influence.

Artificial intelligence, to those who don't use it every day, seems like a concept belonging to grandiose movie productions or science fiction books. But the truth is that it is a collection of almost century-old concepts that are increasingly common and that we often rely on without even realizing it. Find out what artificial intelligence is, what it is for, what its risks and challenges are, and what we can expect from it in the future. Artificial intelligence is not about creating new information, but about collecting and processing information to use it to make decisions in the best way. Artificial intelligence has become a huge and revolutionary tool with countless applications in our daily life. Artificial intelligence, capable of generating robots that act with human reactions and respond to voice requests through practical functions of mobile phones and speakers, has attracted the attention of information and communication technology (ICT) companies around the world and is considered the fourth technological technology revolution since the proliferation of mobile and cloud platforms. Despite the innovations it brings to our lives, its history is a long process of technological development.

The idea of creating machines that imitate human intelligence existed already in ancient times, when there were myths and legends about automata and thinking machines. However, their true potential was not explored until the mid-20th century, when the first electronic computers were developed in 1943. Warren McCulloch and Walter Pitts presented their model of artificial neurons, which was considered the first artificial intelligence, although the term did not yet exist. Later, in 1950, British mathematician Alan Turing published an article in Mind magazine titled "Computing Machines and Intelligence" asking the question: Can machines think? He proposed a test that became known as the Turing Test, which the author claimed could determine whether a machine could have human-like or indistinguishable intelligent behaviour. John McCarthy coined the term "artificial intelligence" in 1956 and led to the development of the first artificial intelligence, the LISP programming language, in the 1960s. Early AI systems were rule-based, which led to the development of more complex systems and increased funding in the 1970s and 1980s. Artificial intelligence is now experiencing a renaissance thanks to the development of algorithms, hardware and machine learning techniques. As early as the 1990s, advances in computing power and the availability of large amounts of data allowed researchers to develop and build learning algorithms for the current artificial intelligence. In recent years, this technology has exploded, greatly stimulating the development of deep learning, which uses layered artificial neural networks to process and interpret complex data structures. This development has enabled disruptive AI applications, including image and speech recognition, natural language processing and autonomous systems.

Artificial Intelligence in Construction Materials

In recent years, the global digitization of business processes and concepts, such as the development of digital technology, has accelerated and is growing so fast that the construction industry is struggling to keep up with the latest developments. A giant digital technology, artificial intelligence, is considered an integral part of the digital transformation paradigm and has been widely adopted across industries. Artificial intelligence is also expected to open several new possibilities in the planning and construction of construction projects. Get better information about research trends and developments in the application of artificial intelligence technology in the construction industry.

Modern living is based on building materials that are used over large areas and generally have a long service life. Since building materials are an integral part of everyday life, their mechanical performance, durability, resilience and adaptability for construction are central to materials research. Deformation and degradation of building materials due to external loads and environmental degradation are always caused by intermolecular interactions. Recent advances in nanotechnology have enabled the investigation of complex processes and failure mechanisms in material systems at the nanoscale, which has fundamentally helped to produce reinforced materials with distinct properties and inspired structural design added advanced materials such as carbon-based additives, new construction materials, can expect better results in the design, which is also the reason why nanotechnology should be applied in the development of construction materials. However, the design and production of building materials often involves multiple components (i.e. cement-based materials, composites, metallic materials and natural materials such as wood and bamboo) and interdependent environmental conditions (i.e. short-term and long-term performance of buildings). In addition to the traditional high expectations of strength and durability, the influence of building materials on the building structure has several aspects, such as construction schedules, energy consumption, carbon dioxide emissions, aesthetics and thermal comfort. Therefore, the influence of many influential factors in the optimization of building materials complicates traditional approaches to find an effective material recipe. In addition, traditional methods require many trial and error cycles in experiments and simulations, which are labour-intensive, time-consuming and resource-intensive to improve even a single function. The recent explosion in artificial intelligence technologies can significantly change and improve the role of computers in science and technology.

Artificial intelligence is a branch of computer science that aims to create intelligent machines that can perceive, make decisions and solve problems. Machine learning, especially deep learning, is one of the essential branches of artificial intelligence that derives mathematical models that can directly perform specific tasks (eg, generation, prediction, improvement, clustering, and dimensionality reduction) from collected data (eg, data tables, graphs and images) using computer algorithms. These techniques are well suited to solving complex problems involving a large number of combinatorial spaces or nonlinear processes that cannot or cannot be solved by traditional approaches at higher computational costs. The Intelligent Building Materials Ecosystem is an attractive application of artificial intelligence technology that integrates material information from various data sources and the background of its applications to pave the way for the development of new generation personalized materials. Aiming to uncover predictive qualities both within and between categories, utilizing a variety of extra information from multimodal data allows for objective, automated research and design of novel construction materials.

Advances can be made using enough datasets of building materials to identify patterns in the data using unsupervised learning, predict properties, or create synthesis instructions for new building materials using supervised learning. Unsupervised learning uses only machine-readable representations of data to find patterns and contrasts (such as extreme data points or clusters) between different cases. Supervised learning is a common and powerful machine learning technique widely used in material research related to artificial intelligence. Supervised learning involves a training procedure that determines mappings between representations, attributes, or synthetic outputs to create surrogate models of predictors. Significant progress has been made on these materials in recent years using various algorithms, which include regression methods, tree methods, and neural network methods. The inverse problem is an active and leading research topic in the current scientific environment, which suggests strategies for tailoring materials or synthesis plans to achieve a material performance goal. Along with more traditional methods such as active learning and evolutionary algorithms, generative models are advancing in the field of materials, which facilitate the search for suitable materials in the hidden space of the proxy and provide effective material design optimization. The proposed candidate materials are then evaluated in simulations and experiments, which are then added to ever-expanding datasets. At the same time, computing and laboratory infrastructures are being developed in the integration of artificial intelligence technologies. The agents of artificial intelligence, which learn the input-output behaviour of simulation software, are computationally many times more efficient compared to traditional methods. Control with machine language functions has also begun to have a significant positive impact on the efficiency of material synthesis and characterization devices. Such human-machine collaborations are expected to evolve into material-sensitive digital assistants with continuous and autonomous learning capabilities and understanding of construction materials. Due to their strong learning capabilities, AI agents are expected to continue to grow and be associated with construction and industrial data to further improve automation and material design autonomy. Industry 4.0, commonly referred to as the "Fourth Industrial Sector" describes the application of cutting-edge digital technology to develop traditional industrial practices and production techniques into autonomous intelligent systems. With this idea, the combination of CMIE and Industry 4.0 can further promote productivity, precision, efficiency and construction safety. CMIE forms the framework for the future direction of building materials Industry 4.0. Industry 4.0-CMIE redefines the relationship between the optimization of building materials and the building itself by realizing the integration of material optimization systems, cyber- physical systems, industrial production systems and digital and computing technologies design, construction, operation and maintenance can be treated holistically by simultaneously optimizing the performance and durability of materials. It is possible to fully handle the design, construction, operation and maintenance of buildings while maximizing the efficiency and durability of materials through the integration of the Industry 4.0 framework. Material design systems include modeling, experimentation, and AI-related assistive technologies (eg, ML and DL). Smart sensors, actuators and the Internet of Things (IoT) are all components of cyber-physical systems. The industrial production system involves the outsourced production of building materials with pre-fabrication and assembly and 3D printing technology. Big data and cloud computing, information modeling systems (BIM), digital twins and augmented reality (AR) are examples of digital and computer technologies. This digital transformation of building materials accelerates the progress of Industry 4.0, which can effectively help create revolutionary architectural and structural design, further improve the safety and efficiency of construction and operation, reduce energy consumption and costs, improve payback time and build sustainability.

Industry 4.0 and Construction

Industry 4.0 has recently been a popular term to describe the transition to digitization and automation in the industrial world. Compared to innovations in other industries, the construction industry has been slow to integrate these revolutionary developments in its standard procedures, due to the rapid advances of other industries and COVID-19, which undoubtedly increased the urgency of the task. Despite the many benefits and opportunities, the construction industry faces many barriers to adopting IR 4.0 due to a number of factors.

Construction is one of the world's largest industries, and its manufacturing base is a pillar of economic growth and competitiveness. According to the World Economic Forum, the construction industry accounts for 6% of global GDP and more than 8% of developing countries. According to (McKinsey, 2018) global construction investment was 11 trillion USD in 2017 and is projected to grow to 14 trillion USD by 2025. The construction sector is at a crossroads; it is both economically important for the growth of the country and plays a key role in our daily life. Despite this, the industry is dominated by, among other things, low\inefficiency, minimal mechanization/computerization and the use of robots. Digitization, automation and convergence enable efficiency and better design and development production. However, the construction industry is reluctant to embrace emerging technology and automation. In general, the construction industry faces some serious challenges such as resistance to reform, barriers to growth, weak competitiveness, predictability, income and recruitment of professional workers and retention problems, which are aggravated by the negative image of the industry (Farmer, 2016; Gerbert *et al.,* 2017; Global Industry Council, 2018; Sawhney *et al.,* 2014; The Business Roundtable, 1983; Witthoeft *et al.,* 2017). Because it can improve the efficiency of the organization and bring a new element traditional way of working, digitalization has become a generally accepted paradigm worldwide. Digital technology (DT) has had a major impact on the day-to-day operations of many traditional businesses. Most expertise sectors, such as the construction industry, have been transformed by easy access to information and faster communication speeds (Wong *et al.,* 2018). Therefore, the successful adoption of new innovations has a significant impact on economic growth. However, in terms of technical progress, the construction sector lags behind large industries (Nasseredddine *et al.,* 2020). However, several digital innovations such as BIM, machine learning, 3D printing and robotics are expected to be integrated into its business processes in the next 3-10 years. Unlike other industries, the construction sector has become a digital laggard (Agarwal *et al.,* 2016; Friedrich *et al.,* 2011). Researchers and professionals alike have recognized the need for faster digitization of the AEC industry. In addition, this year's COVID-19 pandemic has changed the way; the consequences of the Pandemic will affect several business developments in the future Construction sites will develop with the help of digital technology, which will improve the possibility of winning contracts and increasing the profit margin. The positions of business experts and frontline workers change as a result of changes and revolutions (Bigrentz, 2021). While most other industries have experienced major changes in recent years, the construction industry has slowly fully embraced new technology. The lack of digital transformation in the construction industry may be due to a lack of commitment on the ground, a workforce with limited access to modern technology, and broken relationships (Friedrich *et al.,* 2011; Leviäkangas *et al.,* 2017). In addition, construction companies had to deal with multidisciplinary PESTEL challenges (political, economic, social, technological, environmental and legal) challenges. Therefore, it is our own responsibility to promote its digitization to prepare it for the dawn of the 20th century, especially after the COVID-19 pandemic the construction industry is aware that it must think about work processes to work smarter and more efficient.

Automation in Construction Industry

Although the development and implementation of automation technologies has developed more slowly in construction than in manufacturing, the time is ripe for automated construction technologies to play an important role in the full flowering of the digital transformation of construction. Constantly evolving, the construction industry on automation in its many forms, from automated digital design and analysis processes to the automated creation of construction documents and ultimately construction operations. Automation of construction processes, whether in prefabrication that mimics advanced manufacturing best practices, or on-site construction robotics is a key to the success of the construction industry to meet the challenges of the 21st century: the high demand for buildings infrastructure and the need for sustainability throughout the life cycle. Similar issues and problems that automated manufacturing processes have helped other industries solve can also be addressed by building automation. These issues and problems include lead times; material efficiency, labor productivity, worker health and safety, and the ability to make up for labor shortages, lessen environmental effects, and create new project opportunities.

Simply put, the automated construction industry has the opportunity to safely meet the global construction and infrastructure needs of a growing population. New technological developments and industry trends indicate that now is the time for automation to take over.

The term construction automation includes processes, tools, and equipment that use automated workflows to construct buildings and infrastructure. In some cases, tools are used to automate work currently done manually and in other cases, automated tools enable new processes implementation or development especially in construction. Construction automation can happen at different stages of a project starting from the software-based design stage and continuing with automated parts, off-site and on-site construction work, and to end with the sharing of collected information about the systems and energy use of the finished buildings, all stored in cloud-based housing models. Several key development strategies are required to implement this integrated feedback both in software and hardware. The technologies and approaches that make building automation a commonplace reality include collaborative robotics; industrial construction tactics; new kinds of robots and automated equipment; and real-time location detection, feedback, and adaptation.

Industrialized Construction (IC) is a term used to define the strategic deployment in materials, processes and systems construction processes in a way that considers manufacturing. Industrial construction is not synonymous with construction automation, but the two are essentially connected as the increased adoption of automated tools allows industrial construction strategies to radically affect the way construction is done. Nowadays, industrial construction mostly refers to exterior construction, where the use of manufacturing technology\in the built environment is more widespread. Industrial construction processes produce elements of buildings and infrastructures from individual parts to components\or complete assemblies, using techniques and strategies usually reserved for manufacturing processes. In volumetric industrial construction, complete volumetric modules - such as complete hotel rooms - are manufactured in a factory-like environment and then transported to a construction site to be assembled into a complete building. Because its origins are in manufacturing industrial construction is based on reliability, safety and quality, reliability provided by predictable variables not found in traditional construction, and the ability to use advanced, highly automated manufacturing techniques. These are not new ideas - examples are from the origins of the built environment - but now an unprecedented convergence of technologies increases the value and impact of IC strategies between industries. Automated industrial construction processes, traditional paper drawings can be deleted because data from 3D models and more from digital objects goes directly to an automated production line for production. Production lines may contain industrial robots, balancers, conveyors or other automated devices that perform the translation of materials into construction components and assemblies. It is important to assess automation opportunities as they relate to environmental impacts; employees; and of course, return on investment.

Robotics in Construction

Robots, especially industrial robot arms and mobile robot platforms, play an important role in the construction automation debate. The future may be imagined with construction specific robots, but today manufacturing based robots are moving towards construction. Companies like ULC Technologies develop special solutions and integrate industrial robotics into work cells suitable for construction sites. For example, its road and trench system make automated, surgically precise repairs to underground infrastructure with minimal disruption. Collaborative robots, or cobots, are robots of various levels that work together with humans. Cobots usually come with safety standards with some redundant safeguards to make sure they don't harm anyone. Construction robots can be designed specifically to navigate the uncertain and ever-changing environment of an active construction site. An example of human-robot collaboration on site is the Construction Robotics (CR) SAM100 (Semi-Autonomous) Mason) masonry robot. This robotic system works with construction workers to make their jobs faster, less stressful and less repetitive. The SAM100 includes the mason's work setup and final wall quality assessment, while the SAM separates and places the individual masonry.

A construction robot refers to robotic devices developed for a specific construction-related activity. The introduction of a construction robot is not a new approach, as its use was first identified in Japan in 1983 and became popular in the 1990s, when nearly 150 construction robots were developed covering a huge variety of construction tasks. The term "Single-Task Construction Robots (STCRs) was first defined by Bock and Linner

(2016), who also defined the typology, application classes, and mechanical properties of STCRs. An STCR typically consists of three main parts: an airliner, manipulator and final power. STCR is typically a standalone system developed for a specific construction task, reflecting the practical needs of the construction professional and used in a coordinated environment. Overall, STCR can beat man hours and provide consistent quality; however, when a robot is used with insufficient automation or improper operation, the profit and gain often offset the additional tasks required to install, calibrate, and operate the robot. The progress of automation and robot technology has improved the overall performance of many industries, such as manufacturing, has improved its productivity, quality and work environment after the introduction of highly autonomous production lines. However, there are fundamental differences between the construction and manufacturing industries, such as work methods, sensor technology, human collaboration and know-how. These differences determine the differences in design specifications, user experience, mechanism selection and kinematics between industrial robots and STCR. Although a robot may be able to perform many of the construction tasks that humans once did, there are many trade-offs when applying robotics to construction without considering human-robot attributes. For example, robots can outperform humans in repetitive and physically demanding tasks and provide greater efficiency, endurance and accuracy. Conversely, humans can override robots when making decisions in an unfamiliar situation. He also has the ability to learn and adapt to changes in given instructions and process new information accordingly. The STCR designer must be aware of the optimal level of automation they should assign to the robot and what tasks can be done more efficiently by a human and therefore should be manual. Robot design must strike the right balance between the distribution of functions and the level of complexity to achieve the desired level of automation, rather than creating a robot that is too complex to function. Humans and robots complement each other's activity; but robots do not eliminate the need for humans (Pan, 2020).To fully understand how construction was traditionally done, it is important to implement the appropriate level of automation for a specific construction task. Unlike the manufacturing industry, where most tasks are performed in a controlled environment such as a factory floor, construction work is often performed in an unpredictable environment, exposed to external factors such as rain, wind, snow and sunlight. Although some construction jobs are repetitive and thus facilitate the introduction of robotic technology, the process can nevertheless be very dynamic, with many tasks performed by different trades in parallel. The aforementioned factors make the adoption of robots particularly difficult for the construction industry. Therefore, the successful automation of the on-site construction task requires that the STCR designer has a thorough knowledge of the existing workflow, as well as an awareness of work tools, data transmission methods, collaboration between different industries and the decision-making process task (Price and Pulliam, 1982). A South Korean consortium recently developed a robot on a platform to assist a human in dealing with a curtain wall (Chung, *et al.,* 2010). In the European context, an example is the installation of a facade sandwich panel with a robotic truck crane, which was prototyped by a research institute in Slovenia (Činkelj *et al.,* 2010). During the renovation of the facade, robotic arms in addition to moving platforms performed positioning and insulation operations. Brunkeberg has developed an innovative method for supplying and installing curtain modules (Brunkeberg, 2021). The Brunkeberg system shows a technological achievement in the installation of building facades. Installing curtain walls also has the same challenges as mentioned before; for example, harsh working environment, communication breakdown between different sectors, unreliability of supplies and availability of skilled labour and cranes (Eisele and Kloft, 2003). The integrated system consists of five main elements, including vertical profiles, transport systems, lifting systems and lifting systems. The main advantage of the systems is the minimization of on-site tasks such as panel staging, material handling and lifting. It digitally manages the installation process, providing better transparency of information to stakeholders. The system was tested in a case study building in Sydney and achieved productivity gains of up to 25% and project cost savings of up to 5%. The challenges facing the system are the limitations of the available traffic. For example, delivery vans must be modified to be able to load and deliver oversized facade panels. Because the loading area is close to the building and vertical transport requires a pre-assembled vertical profile. In addition, there is a risk that the ongoing operations of other industries will also be disrupted. Despite the challenges, the system laid the foundation for the automation of the installation of building facades (Friblick *et al.,* 2009).

Artificial Intelligence-Assisted Building Design

The tools and methods used by architects have always influenced the design of a building. With the change in design methods and a new approach to the creation process, they became more central to the creation process than ever before. Automating the work of architects began\with computer functions introduced in traditional computer design tools.

Today, architects tend to use specific tools that suit their specific needs. In some cases, they use artificial intelligence. Despite many similarities, they have different advantages and disadvantages. Therefore, changes in the design process are more visible and invisible until the solutions are of the field. The article presents methods for applying selected algorithms of artificial intelligence: swarm intelligence, neural networks and evolutionary algorithms in the architectural practice of the authors. In addition, research shows methods of analog data input and output approaches, based on vision and robotics, which in the future, together with intelligence algorithms, can simplify the daily practice of architects. The presented techniques allow creating new spatial solutions with relatively simple intelligent algorithms, many of which can only be implemented with special software. The popularity of the following methods among architects leads to the use of more intuitive general purpose design tools.

The tools architects' uses are constantly evolving Sketches, 2D drawings and physical models to create more accurate design tools for specific solutions. Modern architects often use a complex computer system to create complex forms and provide the means to freely control and change them. However, most digital tools for designers available today are limited to preset commands. Contrary to the complex architectural vision, a narrow set of tools motivates designers to create their own algorithms based on previously different disciplines. Most of them are based on a hierarchical and almost linear approach to the creative process. However, more and more attention is being given to ewer design techniques\rather than a heuristic approach. By changing the process of creating insight, they allow creating informative and architectural views of non-hierarchical significantly different approaches to solving problems. In general, this approach is based on unanticipated assumptions. However, a non-hierarchically created form can be based on computer learning, which induces the artificial intelligence of the discipline. The change can be seen in the modern approach to creating forms. Designers create their structures based on provided input data that can be gathered by traditional non-computing means or advanced automated computing systems, rather than relying on their subjective personal artistic vision. Both algorithmic and data-driven methods have resulted in a form creation process that is fully customizable through all stages of design. It is important to note that all algorithms and methods are guided by the designer, who is responsible for the actual, full-scale architectural form based on his experiences and preferences.

Artificial Intelligence in Fabrication and Construction

Over time, the construction industry has experienced many technological advances, from the way buildings are designed to the way materials are manufactured and combined into buildings. If we think of CAD, 3D models, environmental modeling and more BIM and VR, or hand tools to power tools to robotics, on site, instead of hand-drawn plans to construction to outsourcing, etc. Every groundbreaking technological change has brought with it more efficient and effective ways to design and construct buildings, evaluate performance, and even disrupt contemporary standards to some extent. Today there has been a transition, or potential transition, from Computer-Aided Design (CD) to Algorithmic Design (AD) in a very short period of time, from machine learning (ML) to artificial intelligence (AI), natural language processing (NLP) to generative artificial intelligence (gen AI) and AI general intelligence. Although many of these technologies are not yet fully main stream, there is already a long list of AI building design tools that are readily available and the changes or possibilities are significant. The promise of such new innovative technologies is to improve efficiency, production and safety. What is clear is that they are becoming disruptive technologies at all levels of the construction industry, from planning to design, detailed project assessment, design and evaluation, material recovery and production, selection, production and construction processes to construction management and construction. Artificial intelligence engineering and design can use algorithms that can analyse massive amounts of data to help architects and engineers create smarter designs. While machine learning algorithms can help predict potential project risks and identify areas for improvement, virtual reality simulations produced by artificial intelligence allow stakeholders to visualize projects before final decisions are made, potentially reducing the potential for design errors and therefore risk. Project management artificial intelligence can potentially help optimize project schedules and resources, while natural language processing (NLP) algorithms enable automated analysis of various project documents such as contracts and permits. In turn, analytical tools can help with valuation, cost, value creation, carbon input estimation and more. In terms of security and risk management, AI has the potential to assess site-related issues and further extend the algorithm tools already in use, such as agent-based modelling, which can estimate the potential behaviour of both site workers and final occupants in fire scenarios. Smart devices, such as smart hats, can also help directly detect hazards and alert workers in the workplace.

The use of wearable sensors and helmet cameras can help monitor and review workplace processes, safety measures and adherence to protocols. The same tools and artificial intelligence algorithms help analyze images to identify structure and defects and improve quality processes and failures and general inspections. Already deployed AI robotic survey and construction tools can perform increasingly repetitive construction tasks and evolve through learning while maintaining quality control, potentially continuously and more efficiently and accurately than human workers. While equipment sensors can help monitor the performance of mechanical machines and prevent downtime due to errors and breakdowns. Artificial intelligence is now revolutionizing and will continue to revolutionize the construction industry, from the earliest stages of planning and procurement to the way buildings are manufactured, reserved and used. The potential lies in achieving unprecedented efficiency and productivity. It seems clear that such changes in such a short period of time and across the entire spectrum of construction processes are unprecedented and can disrupt other normal changes as well. Change has both positive and negative aspects, depending on one's perspective.

Before commencing a commercial construction project, representatives and groups from various fields and areas of expertise must collaborate to plan the course of the project. This is crucial. Pre-construction, as it is called, refers to the stages of construction that take place before the actual construction work begins. Pre-construction entails the participation of building owners, architects and engineers, contractors, general contractors (who design/build entire buildings), building product manufacturers, and many others. The commercial construction preconstruction process helps ensure that the project is completed on time, on budget, and to the client's satisfaction by identifying and addressing the sequence of people and events that complete the project. As with ongoing projects, proper site work in pre-construction contributes greatly to the strength of the project. Pre-construction stages vary depending on variables such as the type of building or project (eg, hotel, school, road, or bridge), the methods of project execution, the scope of the work, or whether it is public or private construction project.

The construction industry is embracing more AI-driven tools and techniques, which has led to a positive development in the field's present and future. As technology advances, AI is expected to become an even more integral part of the construction process, helping to improve efficiency, reduce costs and improve the performance of construction operations

Smart Infrastructure and Artificial Intelligence

Artificial Intelligence enabling smart urban solutions brings multiple benefits, including more efficient energy, water and waste management, reduced pollution, noise and traffic congestions. Local authorities face relevant challenges undermining the digital transformation from the technological, social and regulatory standpoint, namely (i) technology and data availability and reliability, the dependency on third private parties and the lack of skills; (ii) ethical challenges for the unbiased use of AI; and (iii) the difficulty of regulating interdependent infrastructures and data, respectively.

Among other things, AI applications can improve and upgrade water and energy infrastructure, city services, and foster strong and resilient communities in smart cities. However, local governments, citizens and other smart city stakeholders face several challenges when implementing applications.

Cities face major challenges to accelerate the energy transition, such as limited space availability, scarce labour capacity and materials, and limited financial resources. To achieve climate goals5 and accelerate the energy transition, massive renovations and construction works are inevitable. AI gives local governments, construction companies, power companies and other stakeholders the opportunity to respond to these challenges. For example, spatial object detection based on satellite images, artificial intelligence with machine learning for route optimization can optimize infrastructure planning in limited space and support work prioritization and limited labour and material. Achieving climate goals also requires that cities use all available local sources of sustainable energy and create local energy systems with distributed renewable energy sources that periodically affect the grid. For example, innovative 5th generation district cooling networks aim to integrate heat and electricity as energy carriers for climate neutral heat and power production in the built environment. In addition, these networks connect urban water networks as a potential source of low-temperature heat, creating integrated multi-use networks in our cities. To support distribution system operators and energy suppliers, the application of artificial intelligence can help to understand the interconnected energy networks and support the cost-effective management of these networks. This requires integration into smart grids, with an important role for integrated AI applications that can act as a link between previously separated infrastructure systems in terms of design and operation and fill the gap created by the lack of energy monitoring and control at the local level. AI-enabled smart grid capabilities include forecasting renewable energy production from intermittent sources such as solar and wind, as well as other distributed sources such as geothermal and hydrothermal energy to improve capacity utilization and network management. On the consumer side, machine learning can be used to predict and break down energy demand to achieve better energy efficiency, while AI-driven consumer energy management also enables demand management due to network flexibility. Together, these applications make the grid more resilient to distributed uninterruptible generation, enabling the use of renewable energy while helping citizens pay for flexible and efficient energy consumption patterns that benefit households and the grid. Examples include Quby in the Netherlands, part of Eneco and develop these services for companies in the industry Tado7, located in the Netherlands, Belgium and Spain and Germany.

Intelligent infrastructure and asset maintenance combines computer vision and automated unmanned aerial vehicles. Vehicles (UAV or drones) e.g. distributed energy production devices (urban wind turbines that can be installed hazardous locations such as towers and bridges, integrated solar energy (PV) on residential facades), water treatment plants, roads, tunnels and bridges. The AI application contributes to damage detection, damage prediction, damage classification, damage localization, condition assessment and lifetime prediction. This requires accurate and real-time information about the condition of assets, the use of those assets and the environmental factors affecting those assets. Although the urban energy networks will undergo major changes in the coming years, the water networks also require sufficient attention. A total of 3.5 million kilometres of water pipelines in Europe, often with significant sections in need of dramatic upgrading, can present significant challenges and threats to energy services to maintain sustainable water and wastewater. These measures require up to €20 billion\year, and challenges such as wind gusts and increased water demand require measures to increase the efficiency and sustainability of the water network. Applications of artificial intelligence can play a role in answering these challenges, such as algae detection and prevention in the field of predictive maintenance of intelligent water networks. Rome's water system leaks over 44% of the time, which is intolerable given the rising demand for water and the need for water regulation in the summer of 2018. Other applications of AI include better management of watersheds, e.g. water quality and flood and pollution prevention, demand side water efficiency, draft forecasting and planning and adequate sanitation.

Ethical and Societal Implications of Artificial Intelligence in Construction

The growing use of artificial intelligence technology in organizations is affecting how people experience work (World Economic Forum, 2018), including how and whether they experience meaning in their work. Artificial intelligence is the ability of computers and other artificial intelligences to do things that would normally be classified as requiring intelligence if a human were to do it, such as reason, planning, problem solving, and learning from experience (Wang, 2019). Meaningful work is the perception that one's work has value, meaning, or a higher purpose (Michaelson *et al.,* 2014) and typically involves the coordinated practice of diverse and complex skills for the benefit of others. Providing opportunities for meaningful work supports positive employment outcomes (Allan *et al.,* 2019) and is an ethically important basis for human well-being and flourishing (Bailey *et al.,* 2019; Lysova *et al.,* 2019). Despite the fact that the use of artificial intelligence is becoming an increasingly common feature of workplaces, how the use of AI affects opportunities for meaningful work and the ethical implications of such changes are still poorly understood. Historically, technological development has changed significantly since at least the first industrial revolution opportunities for meaningful work by changing the activities of employees, the nature of their skills and the feeling of exclusion or integration into the production process (Vallor, 2015). The use of AI is likely to amplify such changes, but its unique properties and uses also create new and controversial implications for meaningful work. Optimistic views suggest that AI will expand significant high-level human jobs (WEF, 2018), while more pessimistic views suggest that AI will undermine and even eliminate human jobs (Frey and Osborne, 2017). These ongoing tensions point to a lack of conceptual clarity about the impact of AI on meaningful work, leading to calls for more research in this area (Parker and Grote, 2022).

Current AIs are narrow AIs or artificial intelligences that can only perform actions in limited domains, such as classifying images of cats (Boden, 2016). The "holy grail" of AI research is general artificial intelligence (Boden, 2016), or artificial intelligence that can perform at least as well as humans in all intelligent activities. We focus only on narrow AI, as it is used in many other fields, including healthcare, justice, education, manufacturing and military contexts (Bankins and Formosa, 2021; Bekey, 2012; Walsh *et al.,* 2019). The established use of narrow AI also allows us to use practical examples to assess its impact on meaningful work. While general AI has the potential to make significant contributions to meaningful work, there is a lack of consensus on when this will happen. Hence, it is essential to analyze the influence of present-day AI characteristics on significant employment opportunities that arise in the immediate future. Previous studies show positive and negative aspects of the impact of the technology. meaningful work. For example, the use of technology can increase the professionalism and autonomy of employees, but it can also reduce skills and help control them (Vallor, 2015; Mazmanian *et al.,* 2013), and meaning usually increases in the former case (Cheney *et al.,* 2013). al., 2008). While technology can help people maintain their current beliefs about meaningful work, it can also have unintended consequences, such as providing on-demand access to work and a rise in distractions of other bonds (Symon and Whiting, 2019). Such dual effects are still evident in emerging forms of technology, such as workplace robotics, which offer both benefits and threats to meaningful human work (Smids *et al.,* 2020).

Future Perspectives and Trends:

Construction has long been associated with crafts, traditional methods and other forms of craftsmanship. But the winds of change are blowing through the industry and ushering in the age of artificial intelligence. AI is changing every aspect of the construction industry, from autonomous devices to predictive maintenance, design optimization and projects. We explore the benefits, challenges and ethical issues associated with artificial intelligence in the construction industry. This technology can improve the efficiency, safety and sustainability of future infrastructure. Come with us on this exciting journey into the world of artificial intelligence applications in construction.

Artificial intelligence is having a profound impact on construction, changing the way projects are designed, planned, managed and executed. Technologies and tools based on artificial intelligence are the future of construction, increasing efficiency, safety and sustainability. Construction companies will benefit from adopting artificial intelligence in the construction industry to deliver projects on time, on budget and with higher quality.

Construction expenses can be reduced by as much as 20 percent through the use of robots, artificial intelligence, and the Internet of Things. Engineers can use virtual reality glasses and send mini robots into buildings under construction. These robots use cameras to monitor work progress. Artificial intelligence is used to direct the electrical and plumbing systems of modern buildings. Companies are implementing artificial intelligence to improve safety protocols at construction sites. Artificial intelligence is used to monitor real-time workplace interactions between workers, machines and objects and to alert supervisors to potential safety issues, construction defects and productivity issues. Despite predictions of massive job losses, artificial intelligence is unlikely replace human labour. Instead, it will transform the business models of the construction industry, reduce costly errors, reduce workplace accidents and make construction operations more efficient. Construction company leaders must prioritize investments based on areas where AI will have the greatest impact about company's activities unique needs. Early adopters set the direction of the industry and benefit both in the short and long term.

The Conclusive Role of Artificial Intelligence in Industry Construction Materials

Construction has always been one of the most labour-intensive industries, requiring significant time, effort and resources. However, the advent of Artificial Intelligence has changed the way we operate in this field. Companies are using artificial intelligence to develop safety systems at construction sites. One of the most important benefits of AI in construction is improved safety. Construction sites can be dangerous and accidents can happen at any time. However, AI can be used to monitor a construction site and detect potential hazards, such as workers not wearing safety equipment or unsafe working conditions. AI powered robots can also be used to perform dangerous tasks that put workers at risk. This can help reduce accidents and save lives. Another benefit of AI in construction is increased efficiency. AI can be used to optimize construction processes, identify bottlenecks and automate repetitive tasks. AI powered drones can be used, for example, to inspect construction sites, monitor progress and collect data. This can help project managers make better decisions and ensure projects are completed on time and on budget.

AI can also improve construction accuracy. Using AI-powered sensors and software, construction companies can collect and analyse information about various aspects of the construction process, such as materials, design and environmental conditions. This can help identify potential problems and ensure that projects meet quality standards. Robots powered by AI can also be used for precision work such as masonry, welding or painting, which can improve the accuracy and quality of construction work. Another important advantage of AI in construction is cost reduction. By automating repetitive tasks and optimizing processes, construction companies can reduce labour costs and increase productivity. AI can also be used to monitor equipment performance and predict maintenance needs, reducing downtime and repair costs. AI-based tools can also be used to analyse data and identify savings opportunities, such as reducing waste or optimizing energy consumption. Artificial intelligence can also play an important role in construction in developing countries. Many developing countries lack the resources and expertise to carry out large construction projects. However, AI can be used to overcome some of these challenges. AI-powered drones can be used, for example, to map remote areas and collect data from construction sites, which facilitate project planning and implementation. AI-powered robots can also be used to perform labour-intensive tasks, reducing the need for human labour.

While AI has the potential to revolutionize the construction industry, there are also some challenges and obstacles that need to be addressed. Here are some main challenges:

1. Implementation Costs: The costs of implementing AI technology in construction can be a significant barrier. Many construction companies, especially small and medium-sized companies, may struggle to justify the initial investment of implementing AI-powered systems and tools.

2. Data Quality and Quantity: AI relies on accurate and abundant data to function effectively. However, in construction, data can be fragmented and difficult to collect. Construction companies may need to invest in data management systems and processes to ensure that data is collected, organized and analysed effectively.

3. Workforce Skills and Training: Developing, implementing and maintaining AI requires specialized skills and knowledge. Construction companies may struggle to find workers with the skills and knowledge to work with AI-enabled systems and tools.

4. Regulatory and Legal Challenges: Like all new technologies, AI in construction faces regulatory and legal challenges. Construction companies may have to meet complex legislative and regulatory requirements to ensure compatibility of their AI-enabled systems and tools.

5. Ethical Concerns: As artificial intelligence becomes more commonplace, there are also ethical concerns to consider. For example, there may be concerns about the displacement of human workers by AI-powered robots, or the possibility that biased algorithms will continue to discriminate.Responding to these challenges is critical to realizing AI's full potential.

While there are no easy solutions, construction companies can overcome these challenges by investing in the necessary infrastructure, training and expertise, and working with industry partners, regulators and other stakeholders to address emerging ethical and legal issues. Overall, AI has the potential to transform the construction industry, increasing safety, efficiency, accuracy and reducing costs. Artificial intelligence can also help in the construction of developing countries, overcoming problems of resources and expertise. As AI technology advances, we can expect even more benefits and opportunities for the construction industry.

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