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# Structural DNA Nanotechnology: From Design to Applications

Bayan Alarishi , Christian Bach
Department of Technology Management, Department of Biomedical Engineering, School of Engineering, University of Bridgeport, 126 Park Avenue, Bridgeport, CT 06604
Balarish@my.bridgeport.edu
Department of Technology Management, Department of Biomedical Engineering, School of Engineering, University of Bridgeport, 221 University Avenue, room 153 Technology Building, Bridgeport, CT 06604
Cbach@bridgeport.ed

## Abstract:

Structural DNA Nanotechnology applies modified DNA strands to come up with various shapes and order of arrangements of DNA molecules as desired. This DNA specimen is produced by exchange of DNA backbones in a reciprocal fashion resulting in systems of branched strands with many helical domains. The DNA strands are joined by cohesions forces at the ends as a result from hydrogen bonds or covalent bonding. They can also be joined paranemically or by sharing the same edges. The process utilizes the ability of nucleic acids to combine only with specific complements hence a DNA sequence can be designed to favor the formation of a particular strand. The difference between naturally occurring DNA structures and artificial DNA is that the junction is artificially fixed at certain point to favor a particular rigid pattern and stability as desired. Structural nanotechnology is based on four basic concepts mentioned below. First, tile based structures; this was the most dominant method of DNA design between 1990s and 2000 and was replaced by DNA origami. In this approach, the targeted structure is broken into smaller sub-units with strong bonding between two strands forming a particular unit while having weak connections between the units. The approach is usually used in making periodic lattice and implementing self-assembly applied in DNA computing. Second, folding structures (DNA origami); it involves making the DNA nanostructure from one long strand of DNA, nucleic acid sequence in this long strand can be designed such that it folds by itself or the folding can be done manually by use a staple strand. The latter method is what is known as DNA origami, which permit creation of 2D and 3D shapes nanoscales. Third, dynamic assembly; in this approach, the intermediate and final product of DNA assembly are controlled all through, the starting materials are made to form a hairpin structure which then assemble in a specific order. The process is isothermal and does not require thermal annealing to trigger the assembly in desired conformation. Fourth, sequence design; this is the final stage done after any of the above approaches have been used, it is done to dedicate a certain nucleic acid base to a particular constituent in the strand so that they assembly in a certain predetermined order. The desired sequence is separated from the undesired by either symmetry minimization or thermally.

**Keywords:** Nanotechnology; DNA origami; DNA folding; DNA design.

Medicine Subject Classification; Library of Congress Classification

Purpose

This paper is targeted to explain the concept of structural DNA nanotechnology, and its applications in DNA modification. Approaches considered in this paper are general to any process in nanotechnology, and they include; tile based structure approach, folding structures approach, dynamic assembly approach and the final stage of every process, sequence design. The methods' efficiencies are determined by how it is applied.

Methodology

The main sources of the information contained in this work are articles published by renowned authors on the subject of nanotechnology and artificial DNA replication. International Journal of Molecular Biology was of great importance as a source document. Other online articles also served as sources providing handy information.

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## INTRODUCTION

Structural DNA nanotechnology involves artificially designing and manufacturing of nucleic acid mainly for technologically purposes(Seeman,1994). In structural DNA nanotechnology, the nucleic acid is treated as non-biological test materials. Through research, static structures such as 2D and 3D crystal lattice have been created, nanotubes and devices functioning at nanoscale such as DNA based and molecular based computer and machines(Simon & Lionel, 2010). Knowledge of biotechnology is applied in crystallography, spectroscopy, and biophysics to identify proteins. Investigation as to whether it can be applied in molecular electronics and nanomedicine are also underway.

Structural DNA nanotechnology focuses on the characteristics of the nucleic acid and synthesis of complexes and materials from the nucleic acid resulting in a static and an equilibrium assembly (Simon & Lionel, 2010). The nucleic acid has a well-defined 3D geometry hence designing of structures that are more complex is possible from the template. Such structures include periodic, aperiodic, 2D, 3D, and discreet structures. Some of the trending ideas in DNA nanotechnology include:

### Extended lattices

Small complexes of nucleic acid can be combined by their sticky ends to form larger 2D structures; such complexes include the double-crossover with four sticky ends. The cohesion scheme is the basis upon which two-dimensional structures have been made (Simon & Lionel, 2010).

### Discrete structures

Research done on structural DNA nanotechnology have led to the synthesis of 3D complexes each with polyhedron connectivity meaning that there is a DNA junction at every vertex(Liu & Yan, 2005). Initially this needed a lot of work as one had to create a catenated polyhedron before proceeding. Subsequent processes have been made easy by folding structure approach.

### Template assembly

The discovery has been that DNA can be made to incorporate certain elements, which are not nucleic acid in nature; this have led to widening of functionalities to a degree that was not possible with nucleic acids only. By using self-assembly, DNA strand is able to replicate these elements(Liu & Yan, 2005).

(Bell et al., 2011; Castro et al., 2011; Chen & Seeman, 1991; Gerdon et al., 2009; Goodman et al., 2005; Högberg, Liedl, & Shih, 2009; Ke et al., 2009; Kuzuya & Komiyama, 2010; Liu, Ke, & Yan, 2005; Nangreave, Han, Liu, & Yan, 2010; Rothemund, 2005; Saccà & Niemeyer, 2012; Schreiber et al., 2011; Seeman, 1999, 2003a, 2007; Shih & Lin, 2010; Steinhauer, Jungmann, Sobey, Simmel, & Tinnefeld, 2009; Tørring, Voigt, Nangreave, Yan, & Gothelf, 2011; Tu, Manohar, Jagota, & Zheng, 2009; Wei, Martin, Rant, & Dietz, 2012; Zadegan & Norton, 2012; Zhang & Seeman, 1994).

### Research Method

### PSY-NANO-SI .

The abbreviation stands for Nanosilicon-Based Photosynthesis for Chemical and Biomedical Applications. This explored how silicon and oxygen interacted and exposed possibilities of applying nano-silicon photo-sensitizers in treating cancer and for protection of the environment(Liu & Yan, 2005)

### NANOCUES

It involved use of cues at nanoscale to direct biological systems in the cell. It aided the developments of biofunctional surfaces that match that of the host while permitting introduction of artificially created properties. Based on this invention, stem cells can easily be studied in experimental situations (Seeman,1994).

### Scientific Model

There are basic approaches that one can be used in structural DNA nanotechnology, these include tile based structure, folding structure, dynamic assembly, and finally system design. The goal of attaining molecules and working on them at nanoscale is achievable by any of the above techniques. The independent variable in the process is the base sequence while the dependent one is the nucleotide order in the compliment. The order of pairing is governed by the model below.

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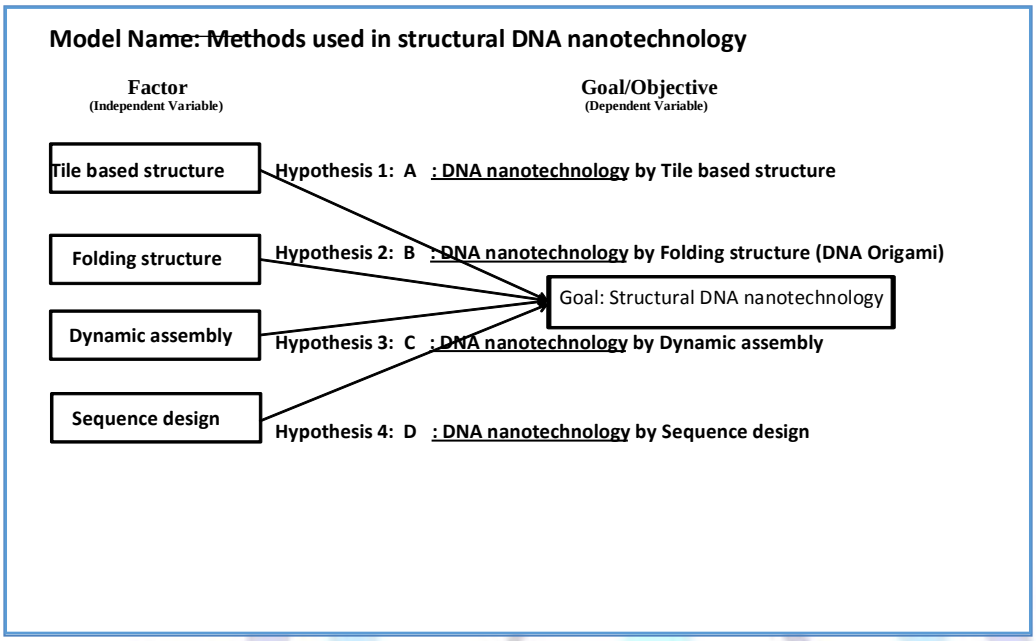
## Scientific Model:: Methods used in structural DNA nanotechnology




## Goal (Structural DNA nanotechnology)

In structural DNA nanotechnology, the nucleic acid is designed such that they assemble in desired order. It begins with specifying the target structure from which the overall structure is constructed. The types of nucleic acid to be used are identified and the specific points where they will be joined are determined. The last step is specifying the sequence to be used as base (Reza & Michael, 2012).

The DNA strand is broken in units with weak joining bonds; additional nucleic acids are introduced at these joints. The resulting DNA strand is an artificial one, due to self-assembly the artificial can replicate into similar one and join with the desired complement according to base sequence. For instance, let nucleic acids A and B to be complimented by C and D. Breaking the between A and B will give space for complementing with C and D.

The second method DNA nanotechnology involves making the strand to contain nucleic acids, which are compliment to each other; the strand can fold by itself making half its length to act as compliment to the other half by introducing shorter strand to complement the long one. For instance, a strand made up of A, B, C and D can twist by itself to complement A with C and B with D

Another way by which DNA strand can be modified is applying chemicals that controls how the nucleotide bond to form a sequence, in this case, all the nucleotides are processes and get bonded to the complement during processing (Reza & Michael, 2012, (Reza & Michael, 2012). Sequence design only serves on all the above methods to sort the desired ones from tertiary ones (Kuzuya & Komiyama, 2010; Liu, et al., 2005; Shih & Lin, 2010; Zadegan & Norton, 2012; Zhang & Seeman, 1994).

## Factor 1 (Tile base structure)

“This strategy dominated between 1990s and 2000s before DNA origami was introduced (Chen,1991).”

“The DNA tile based system has been used to make 3D structures. The first tile based 3D DNA

structure was introduced by Seeman (Zadegan & Norton, 2012) p. 7151.”

It involved breaking the structure into small units, which are weakly bonded to each other. It is often used in the case of periodic lattice DNA computing.

“DNA tile based self-assembly provides an attractive route to create nanoarchitectures of programmable patterns. It also offers excellent scaffolds for directed self-assembly of nanometer-scale materials, ranging from nanoparticles to proteins, with potential applications in constructing nanoelectronic/nanophotonic devices and protein/ligand nanoarrays. (Lin, Liu, Rinker, & Yan, 2006) p.1641.”

(Duong, 1999; J. Hu & Marculescu, 2003; Lin, et al., 2006; Ono, Sumita, & Miike, 1994; Pack, Christopher Jr, & Kawamura, 1997).

## Factor 2 (Folding structures/DNA origami)

“It is called DNA origami and it allowed for creation of 2D and 3D shapes(Reza & Michael, 2012) p. 123.”

"The "DNA origami" method was first proposed and implemented by Paul W. K. Rothemund in2006 , in which he folded a long viral single-stranded DNA (ssDNA) molecule to create DNAstructures of arbitrary shapes. (Zadegan & Norton, 2012) p. 7152."

A long strand is designed such that it can fold by itself by applying shorter strands called staple. (Ding et al., 2010; Han et al., 2011; Maune et al., 2009; Voigt et al., 2010).

## Factor 3 (Dynamic assembly)

"This does not require thermal annealing like other methods of DNA nanotechnology (Goodman, 2005) p.654."

The process is controlled from the start to the end such that intermediate steps in the reactions are specified. The process is isothermal.(Z. Hu, Gogol, & Lutkenhaus, 2002; Kang, Pirskanen, Jänne, & Palvimo, 2002; Mukherjee & Lutkenhaus, 1998; Wittmann, Hyman, & Desai, 2001)

## Factor 4 (Structural sequence)

"Geodetic methods are applied to sort tertiary structures (Simon & Lionel, 2010).p.143."

At this stage, the desired structure is sorted from the rest of the resulting structures. This can be done thermodynamically or by utilizing methods such as symmetry maximization(Seeman, 1999, 2003a, 2007;Tu, et al., 2009).

(Rothemund, 2005; SantaLucia Jr & Hicks, 2004; Seeman, 1998, 1999, 2003b, 2010)

## Explanation/Discussion of Model

The model shows different methods that can be used in structural DNA nanotechnology beginning with the oldest to the newest. Different DNA conformations can be obtained much easier by using diverse methods hence there is a technique that can be used to solve any problem involving nucleic acids design. The accuracy of the methods and ease with which it can be used increases with the invention of more knowledge concerning nanostructures. Currently, dynamic assembly is the newest and most efficient system (Liu & Yan, 2005).

In structural DNA nanotechnology, the design of a nucleic acid should be in a way that allows for the assembling of the model in its desired order. According to the developed model, this process of assembling it begins with the specification of the target structure from which the overall structure is constructed. The types of nucleic acid to be used are identified and the points at which they will be joined are determined. The last step is specifying the sequence to be used as base (Reza & Michael, 2012). This procedure is clearly illustrated in the manner in which the stranding of the DNA nuclei is done in the various factors.

The developed model in this paper assumes that the DNA structure in nanotechnology can be achieved through the uptake of a series of factors as outlined above. In the first factor, the requirement is that the weakly bonded structure of the DNA should be broken so as to enhance the development of 3D structures of the DNA. In this factor, excellent scaffolds are presented which self-directs and self-assembles the nanometer-scale applied in the development. This first factor when incorporated into the model and in determining of the intended structural DNA nanotechnology, the result is the breaking into smaller units of the DNA structural bonding that exists between the two strands of the DNA structure in the model. As a result, it forms a particular unit in the new structure while having weak connections between the units, which enhance the viability of the structural DNA nanotechnology to the model (Goodman, 2005). In this scientific model, the approach of the first factor is usually used in making periodic lattice and implementing self-assembly applied in DNA computing.

According to the second factor, which develops as continuity of the first factor, the DNA nanostructure is made from one long strand of DNA that folds itself in the process. According to this model, the best way would be to design the nucleic acid sequence of this long DNA strand in a way that allows it to fold by itself or have the folding of the strand be done manually by the use of a staple strand (Reza & Michael, 2012). The essence of this factor is that it allows for the permitting of the creation of 2D and 3D shapes of the structural DNA nanoscales. Currently, the use of this method results in complex and highly ordered structures which consists of hundred of thousand of atoms.

The third and fourth factors of the model are greatly enhanced by the achievement made in the first factor. This is because they are both started at the beginning but, allows one to run before the other. In the third factor which is thermal in nature, the intermediate and final product of DNA assembly are controlled all through, and the starting materials are made to form a hairpin structure which then assemble in a specific order (Liu & Yan, 2005).

In the fourth stage, nucleic acid base is dedicated to a particular constituent in the strand so that they assembly in a certain predetermined order. The factor also entails the separation of the desired sequence from the undesired by symmetry minimization.

## Importance of Model/New Insight

The method of structural DNA nanotechnology have evolved from primitive ways to more efficient ones, from the age of tile base structure to folding structure and finally to structural assembly. This shows that there is more room for newer methods. However, introduction of the new method did not wipe out the previous one since the former have its applications that may not be fully implemented in the latter.

This model of DNA nanotechnology is quite significant especially in relation to the presentation of an approach that can address the challenges that usually face the self-assembly of the small DNA molecules into becoming nanostructures that are highly ordered. The application of the factors as enlisted above especially the tile structure allows for ease in the construction of the simple DNA structures.

## Conclusion

As a result of structural DNA nanotechnology, drug delivery may be made efficient by use of nano-vehicles. These vehicles can deliver different kinds of drugs including those with low solubility in water. DNA nanotechnology can also be applied in photonics whereby systems that mimic every aspect of photosynthesis can be developed. Molecular and cellular biophysics are some of the seductive prospects of DNA nanotechnology. However, DNA nanotechnology can be used negatively to develop nano-bombs and elements that can be used against humanity.

In this paper, I have sought to elaborate on the concept of structural DNA nanotechnology with respect to its modifications and applications. As has been presented in the above discussion, there has been tremendous evolution in the method from the use of tile-based structures to the more recent methods, and still there is innovation of newer methods. In this paper, I have also sought to elaborate on the scientific models of the structural DNA nanotechnology, which has only been achievable through the combination of the various factors as independent variables in this case. One thing is quite obvious from the results obtained, which is that structural DNA nanotechnology focuses on the characteristics of the nucleic acid and synthesis of complexes and materials from the nucleic acid resulting in a static and an equilibrium assembly.

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### BAYAN ALARISHI

First term graduate student at the University of Bridgeport, Biomedical engineering Major, Engineering school. Took a B.S. degree in Biotechnology from the University of New Haven, class 2013.

### Christian Bach

Professor Christian Bach serves as an assistant professor of Technology Management and Biomedical Engineering. He holds academic honor as: PHD in information science and executive MBA at Albany/SUNY.