

Delft University of Technology

Feasibility of Quantum Genetic Algorithm in Optimizing Construction Scheduling

Master Thesis

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Abstract

The increasing scale of projects in civil engineering industries leads to the increase of the amount and complexity of data that need to be treated and calculated. As a new non-traditional way of computing, quantum computing shows extremely powerful capabilities in huge data analysis and processing. In this research we focus on optimizing civil engineering construction scheduling using quantum genetic algorithms which have the outstanding performance in optimization and data processing, to create the possibility of dealing with civil engineering problem with quantum computing.

This research consists of an extensive literature study that includes genetic algorithms, quantum genetic algorithms and construction scheduling. Existing applications of optimized design with genetic algorithms and quantum genetic algorithms are the theoretical basis for the hypothesis.

Based on the theoretical research, an improved quantum genetic algorithm which is used for construction scheduling optimization design with the constraints of time and human resourcing is established and named as AQGA (A quantum genetic algorithm). A null hypothesis is taken: AQGA cannot help to improve the optimization design in civil engineering construction scheduling. Then a case study is done with AQGA: through the analogy with flow-shop scheduling, unit construction scheduling is chosen to be processed with AQGA. At the end of the case study, the flowchart of unit construction optimized design with improved quantum genetic algorithm AQGA is given, unit construction optimized design is realized through the improved quantum genetic algorithm

There are some constraints and limitations in the study and research. For example there are simplified and idealized assumptions since a realistic simulation cannot be realized because there is no available quantum computer to run the simulation. But the unit construction scheduling optimize problem is expressed in quantum computing language. It is expected to be a starting point for future application of quantum genetic algorithms within construction scheduling in civil engineering projects and even more broad, quantum computing within civil engineering.

Abbreviations

NP	Non-deterministic Polynomial
GA	Genetic Algorithm
QGA	Quantum Genetic Algorithm
AQGA	A Quantum Genetic Algorithm
MSP	Microsoft Project
FSSP	Flow-Shop Scheduling Problem
PID	Proportion Integration Differentiation

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1. Introduction

The continuous development of the construction and civil engineering industries and the increasing scale of such as PPP projects has become an inevitable trend. The increasing scale of projects will lead to an increased amount of data that needs to be treated and calculated. It shows more and more that using traditional methods to deal with these issues is inadequate, which is likely to become less and less efficient. As a new non-traditional computing method, quantum computing has powerful capabilities in large data analysis and processing. Can this be a linking key point of civil engineering and quantum computing? The focus of this research is to investigate the possibilities of dealing with civil engineering construction scheduling using quantum genetic algorithms because we are motivated by the outstanding performance in optimization and data processing of quantum computing. The possibilities of combining both will be explored, to achieve optimized design of the construction scheduling with quantum genetic algorithm.

1.1. Background

For civil engineering projects, planning and programming of project construction is necessary. Construction scheduling is a key element of the planning and programming of project construction. Construction scheduling is to make technical schedule for provisions of the starting time of construction preparation work and the main project, duration of completion and operation, construction procedures, and strength of construction. It aims to ensure the construction works can be completed according to the contract deadline.(Jiao, 2012) The construction work needs to be carried out in accordance with the arrangements of the construction scheduling.

The principles of construction scheduling are continuity, rhythm and balance.(Jiao, 2012) The establishment of construction scheduling is carried out based on assembly-line principles. There are many planning instruments, and Gantt chart method and network planning method are two widely used methods. The Gantt chart method is condensed and easy to understand but for particularly complex projects, the Gantt chart method is difficult to meet the needs of program management. Network planning methods which make up for the defects of the Gantt chart are being used more in building industry now. And during implementation it can also predict the impact of changes on duration and subsequent work, which is helpful to take timely countermeasures.(Committee, 2009)

Currently, there is an increasing amount of large-scale projects such as skyscrapers and infrastructure projects. In these projects, more arrangements are needed for time and human resource planning. That requires more optimized and efficient design for

construction scheduling to achieve time optimization and maximization of benefits. In the design and construction of the large-scale projects, unit design and construction are more and more used. Units mean some parts which are similar or even identical to each other, like unit façade, unit beam, unit column, unit floor, and so on. These units always have the same structures, same materials, same construction order, etc. For example, unit façade is widely applied in some skyscrapers. Judging from the appearance it looks like assembled by units. Every unit has same structure like column, beam, shaft, box, etc. and same materials like concrete, steel, glass, etc. And they also have the same construction order. For example first vertical columns, second horizontal beam, then sequentially installation of different parts, and so on. For the unit construction if a systematic construction scheduling can be done, it will save lots of time and make the work much more efficient. Unit design can be a simplified and optimized designed for construction scheduling and it also can be a starting point to connect and combine civil engineering and quantum computing, construction scheduling and quantum genetic algorithms.

Now there are some existing optimization methods for construction scheduling such as softwares Primavera, Microsoft Project that are widely used. These softwares have got good management performance, and optimize the progress of the project, which makes the project work more efficiently. However, the optimization methods for construction scheduling can be improved more. Calculation and optimization capacity of quantum computing is often far higher than any of the traditional tools. In fact, the construction scheduling is an NP problem; also belong to multi-objective optimization problem. The NP problem and multi-objective optimization problem can be solved by quantum genetic algorithms.

NP problem is the problem which can be solved with non-deterministic machine in polynomial time.(Yun, 2005) NP means non-deterministic polynomial. If and only if an NP-complete problem L can be Turing-reducible to H in polynomial time, the problem H is NP-hard.(Garey and Johnson, 1979) Typical NP problem includes short-path problem, scheduling problem, graph coloring problem, database search problem, and so on. Construction scheduling of complex projects is also an NP problem.

Quantum computing is a method for performing calculation based on the theory of quantum mechanics. Quantum computing provides new possibilities to solve the complex problems such as the NP problem. Quantum genetic algorithm is a combination of quantum computing and genetic algorithm. Genetic algorithm is a search algorithm used to solve optimization in computational mathematics. In recent years, the genetic algorithms have been successfully applied to reliability optimization, flow shop scheduling, job shop scheduling, machine scheduling, equipment layout, image processing, data mining, and so on.(Mai, T., 2010) With the combination of quantum computing and genetic algorithm has a good ability of solving NP problems like Travelling Salesmen Problem, scheduling problem, knapsack problem, and so on.(Ma and Wang, 2005)

More information about quantum and quantum computing can be found in appendices 1 and 2.

1.2. Problem statement

There are more and more large-scale civil engineering projects and the content related to these projects become more and more, the construction schedule becomes increasingly complex.(Liu, Wang, et al., 2007) In one project, different time and human resourcing planning can be created, and they will lead to different construction results. Therefore, the progress of the project design becomes critical. It is a key point of a project to make the optimal construction scheduling design. To optimize the construction scheduling design, an optimal construction sequence is a very important step for the good completion of a project. Through traditional methods, the optimal one needs to be tested one by one from the huge amount of choices. This requires lots of work and is less efficient, and the optimal construction sequence cannot be found quickly. In most cases, it is not possible to check all of the possibilities. Therefore, construction scheduling design with traditional methods becomes more and more difficult to meet the requirements. However, as the central element of the planning and programming of project construction, it is necessary to find the optimal choice since a successful construction scheduling plan is a very important step to realize a successful project. That will promote the project a lot. To achieve time optimization, maximization of benefits and satisfy clients' different requirements, optimal design of the construction scheduling is required to realize the optimal arrangement of time and human resource planning.

1.3. Research focus

In the first step, the research focus is mainly on the quantum genetic algorithms and what can be solved by quantum genetic algorithms. Then a null-hypothesis will be proposed of a new improved quantum genetic algorithm. At the same time the research focus will shift to the new improved quantum genetic algorithm. The work mechanics and workflow of the improved quantum genetic algorithm will be explained and a case study will be presented to explore how to apply the improved quantum genetic algorithm on optimal construction scheduling design.

The figure1 shows the fields explored and the research focus.



1.4. Hypothesis

There is an algorithm called A quantum genetic algorithm (AQGA). This algorithm is an improved quantum genetic algorithm. The null hypothesis of the research is: AQGA cannot help to improve the optimization design in civil engineering construction scheduling.

1.5. Research method

The existing quantum genetic algorithms will be used as the theoretical base of the research. The existing applications of quantum genetic algorithms will be used as the starting point to discover the possibility of connecting and combining civil engineering and quantum computing. Literature study will be the main method to collect the information and establish the hypothesis and further theoretical analysis. A case study will help to show how to input construction scheduling in quantum genetic algorithm and how to express construction scheduling in quantum genetic algorithm language. Finally we will have our conclusion and recommendations based on the case study, as well as expectations and possible future development.

Due to some limitations an actual quantum computation as a part of the case study cannot be performed. This will be explained in Chapter 1.7.

1.6. Research objective and research question

A proper time and human resource planning is an important start for a project. As mentioned in the problem statement, the research objective is to realize the optimal design of the construction scheduling and to realize the optimal arrangement of time and human resource planning using quantum computing.

Research question:

How to apply quantum genetic algorithm to construction scheduling design?

1.7. Limitations of the research

The biggest limitation of the research is that actual quantum operation and simulation are not available for this research due to there is not an available quantum computer which can run the operation and simulation. In addition, the algorithm used in the process is an assumed algorithm. Although the hypothesis has been done based on adequate theoretical basis from existing algorithms, it still have not been developed yet and there is no detailed working mechanism and functions for every step in the selection process. So if there is an available quantum computer the simulation also cannot be done.

1.8. Structure of the thesis

In this research quantum computing and civil engineering are expected to be combined. After research on lots of applications of quantum computing, quantum genetic algorithm from quantum computing and construction scheduling from civil engineering were chosen to be combined. These are briefly introduced in background in chapter1. And in chapter 1, the problem, research focus, research method, research objective and limitations of the research are also introduced.

In chapter 2, first genetic algorithms, quantum genetic algorithms and construction scheduling are introduced. There is some information about the definitions, working mechanics, current situation, etc. More information is available in the appendix. Then some applications of optimized design with genetic algorithms and quantum genetic algorithms are introduced, including industrialized use, parameter optimization, combinatorial optimization, multi-objective optimization, etc.

In chapter 3, an improved quantum genetic algorithm is established and named as AQGA.

It is used for construction scheduling optimization design with the constraints of time and human resourcing. A null hypothesis is taken for this research and the hypothesis is: AQGA cannot help to improve the optimization design in civil engineering construction scheduling. And the hypothesis is described in more detail. The working mechanics and steps of AQGA are explained.

In chapter 4, a case study is done with AQGA. Through the analogy with flow-shop scheduling, unit construction scheduling is chosen to be processed. A model is built and a fitness function is defined. Then the initial populations will be measured, decoded and evaluated. Populations are updated with quantum rotation gate. Catastrophic operator, crossover operator and mutation operator are used in the process. Then circulatory system is established and starts, until the termination condition is met and the optimal individual is found. At this point, the unit construction scheduling optimization design with AQGA is completed.

In chapter 5, conclusion and recommendations are given. The main research results are summarized and the outlook of further research work is elaborated.

2. Literature study

This chapter presents theoretical understandings of genetic algorithms, quantum genetic algorithms, applications of quantum genetic algorithms, construction scheduling, and the possible connection and combination of quantum genetic algorithms and construction scheduling design. This chapter consists of five sections. The first part and the second part introduce the genetic algorithms, quantum genetic algorithms, and the applications of them respectively. Then construction scheduling and traditional methods of construction scheduling design are introduced. Followed the fourth part some successful applications of optimized design with quantum genetic algorithms are stated, which show the possibility of the combination of quantum genetic algorithm and construction scheduling design. The last part presents the conceptual framework.

2.1. Genetic algorithm

Genetic algorithms are search algorithms used to solve optimization problem in computational mathematics. The genetic algorithm is one of the evolutionary algorithms. It is developed based on some phenomena in evolutionary biology, including genetic, mutation, natural selection and hybridization. The genetic algorithms are usually implemented by computer simulation. For an optimization problem, a number of abstract representations (called chromosomes) of candidate solutions (called individuals) evolve to a better solution. The evolution starts from a population of completely random individuals, and then occurs generation by generation. By the fitness evaluation, a plurality of individuals are randomly selected from the current population (based on their fitness), and new populations are generated by natural selection and mutation.(Melanie, 1999) This process continues until the termination conditions are satisfied. Generally termination conditions are:

- Restrictions on the number of times of evolution;
- Resource constraints on the cost of the calculations(e.g. calculation time and memory occupied);
- An individual has met the conditions of the optimal value, i.e. the optimal value has been found;
- Fitness has reached saturation, continued evolution will not produce better fitness individuals;
- Human intervention;
- A combination of two or more of the above.(Ji, 2004)

The basic operations of the genetic algorithm process are as follows:

- Initialization: Set the evolution algebra Counters t = 0, set the maximum evolution

algebra T, and M individuals randomly generate as the initial population P (0).

- Individual Evaluation: Calculate the fitness of individuals in groups P (t).
- Selection: apply the selection operator to groups. The purpose of the selection is to make the optimization individuals directly to the next generation, or new individual paired cross then inherited to the next generation. The selection is based on the assessment of the individual's fitness.
- Crossover: apply the crossover operator to groups. The so-called crossover refers to the operation of replacing and restructuring the part of the structure of the two parent individuals and generating new individuals. Crossover plays a central role in the genetic algorithm.
- Mutation: apply the mutation operator to groups. That changes the value of certain gene locus of individual string in groups.
- Groups of P (t), after selection, crossover and mutation operation, generate the next generation of groups P (t 1).
- Judgments of Termination condition: if T = T, output the obtained individual with the largest fitness by the process of evolution as the optimal solution, and terminate the calculation.(Ji, 2004)



Figure 2 Genetic algorithm (Yi, M., 2012)

Compared with traditional optimization algorithms, genetic algorithm has a few differences. Genetic algorithm doesn't have a direct effect on the parameter set but uses some encoding of parameter set. The genetic algorithm starts the search from a group of points instead of a single point. The genetic algorithm uses the fitness value without derivative or other auxiliary information. The superiority of the genetic algorithm are, first, it hardly fall into local optima in the search process. Even if the definition of the fitness function is not continuous, irregular or noise, it can also find the overall optimal solution with great probability. Secondly, due to the inherent parallelism, genetic algorithm is very suitable for large-scale parallel computer.(Yi and Liu, 2001)

Genetic Algorithms specializes in solving the global optimization problem. In recent years, the genetic algorithm has been successfully applied to reliability optimization, flow shop scheduling, job shop scheduling, machine scheduling, equipment layout, image processing, and data mining.(Mai, T., 2010)

Genetic algorithm is a bionics algorithm. There is no absolute guarantee for its convergence. It introduces "natural selection" principles into the optimization process. Because it has fewer restrictions for problems such as problem objective function and constraints are neither required to be differentiable nor required continuous, only required to be computable, and it always search throughout the solution space and is able to find near-global optimal solution. It has a wide range of applications in network planning optimization. Compared with other search algorithms, genetic algorithm is computationally efficient; especially for complex planning optimization problem its excellent performance is more powerful. With traditional methods the optimization process easily fall into local minimum plight but GA overcomes that. It is a very effective algorithm with superior performance. It is particularly suitable for solving complex problems.(Wang, Qin, et al., 2004)

2.2. Quantum genetic algorithm

Quantum genetic algorithm is a product of the combination of quantum computation and genetic algorithms. Quantum genetic algorithm is a newly developed optimization method based on the principle of quantum computing. Based on some concepts and theories of quantum computing, quantum genetic algorithm uses quantum bit encoding to represent chromosomes, and realizes the evolutionary search by quantum gates and quantum gates updating. Quantum genetic algorithm has excellent convergence speed and global search ability. And the performance of the algorithm will not be affected with a small population size.(Zhang, Li, et al., 2004) Based on the quantum state vector representation, quantum genetic algorithm applies the qubit probability amplitude to the coding of the chromosome, so that one chromosome can express multiple superpositions. The update of the chromosome is realized by quantum rotation gate and quantum non-gates. In this way quantum genetic algorithm can achieve optimization solution. (Yang and Zhuang, 2003)

The same as the traditional GA, QGA qubit probability amplitude obtain the bits through comparative Law, to calculate the fitness value.(Zhou and Qian, 2008) Yang uses the binary code of genetic algorithm to realize qubit encoding for problem of polymorphic. For example, one qubit is used to encode two states, two qubits are used to encode four states. The advantage of this method is good versatility and simple.(Yang and Zhuang, 2003)

A qubit can be expressed as:

 $| \phi \rangle = \alpha | 0 \rangle + \beta | 1 \rangle$

Where α and β are complex numbers, and

 $| \alpha |^2 + | \beta |^2 = 1$

Where | 0 > and | 1 > denote spin up and spin down states respectively. So a qubit can simultaneously contain information of state <math>| 0 > and | 1 >. Using qubits encoded a chromosome can express multiple superposition, that makes quantum genetic algorithm has a better diversity characteristics than the classic genetic algorithm. Better convergence can also be reached by using qubits coding. With the $| \alpha |^2$ or $| \beta |^2$ tending to 0 or 1, quantum bits encoded chromosome will converge into a single state.(Yang and Zhuang, 2003)

In theory, that anything that can be solved by genetic algorithm is application object of quantum genetic algorithm. (Yang and Zhuang, 2003) Compared with the traditional GA which uses crossover and mutation operation to maintain the diversity of the population, QGA uses quantum gates acting on qubits probability amplitude to maintain the diversity of the population, so the updating of quantum gates is the key of QGA. (Zhou and Qian, 2008) Because qubit chromosomes are able to characterize the superposition state, compared with the traditional GA, QGA has better diversity of population and the ability of global optimization. (Feng and Su, 2011)

Narayanan and Moore proposed quantum-inspired genetic algorithm (Narayanan and Moore, 1996), Han K H and Kim J H proposed genetic quantum algorithm (Han and Kim, 2000) and Han K H, Park K H, Lee C H and Kim J H proposed parallel quantum-inspired genetic algorithm (Han, Park, et al., , 2001). These algorithms are used to solve combinatorial optimization problems. The results show that, the performance of quantum genetic algorithm is much better than conventional genetic algorithm.(Zhang, Li, et al., 2004)

In the computational models of quantum computing and quantum circuits, a quantum gate (or quantum logic gates) is a quantum circuit which has basic operation on a small number of qubits. It is the basis of the quantum circuit, just like the relationship between the traditional logic gates with digital lines.(Nielsen and Chuang, 2000)

Commonly used quantum gates include Hadamard gate, Pauli-X gate, Pauli-Y gate, Pauli-Z gate, Phase shift gates, Swap gate, Controlled gates, Toffoli gate, etc. The quantum gates which are mainly used in this study are the quantum NOT gate and

quantum rotation gate.(Wang, 2009)

Quantum NOT gate is Pauli-X gate. It acts on a qubit. This is a quantum gate equivalent to the logical NOT gate. It can exchange the probability amplitude of I0> and I1>, which means I0> is replaced by I1> and I1> is replaced by I0>, and α I0> + β I1> is replaced by

 $\alpha |1\rangle + \beta |0\rangle$. This gate can be expressed in a matrix: $X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$.

Quantum rotation gate is expressed with matrix as: $U = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix}$. The parameters of quantum rotation gate can be adjusted so it is more versatile. Therefore, in the updating of population of quantum genetic algorithm, the quantum rotation gate is mainly used. The process is as follows:

$$\begin{bmatrix} \alpha_i'\\ \beta_i' \end{bmatrix} = U_i \times \begin{bmatrix} \alpha_i\\ \beta_i \end{bmatrix} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i\\ \sin \theta_i & \cos \theta_i \end{bmatrix} \times \begin{bmatrix} \alpha_i\\ \beta_i \end{bmatrix}$$

In the formula, $\begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix}$ is the qubit before the update, $\begin{bmatrix} \alpha'_i \\ \beta'_i \end{bmatrix}$ is the updated qubit, θ_i is the rotation angle, and its size and direction determine the performance of the algorithm.(Yang, Lin, et al., 2003)

More about quantum, quantum computing and quantum gates please refer to Appendix1 and Appendix 2.

2.3. Construction scheduling

Construction scheduling is a central element of the planning and programming of project construction. Construction scheduling is making construction plans which give the provisions of commencement time, completion time and construction sequence of the various projects. It needs to ensure the completion time of construction works according to the contract deadline. Construction schedule is the basis of the execution of all the construction work.

The process of designing construction schedule is: (Committee, 2009)

- (1) Divide the construction stages
- (2) Calculate workload
- (3) Determine the amount of labor and equipment
- (4) Determine the construction time of different stages (days or weeks)
- (5) Make initial program of the construction schedule
- (6) Check and adjust the construction schedule initial program

Gantt chart method and network planning method are two widely used construction scheduling design methods in practical civil engineering projects. Gantt chart method is a time-tagged tabular form plan. It is a traditional construction scheduling method and it has been use for a long time in civil engineering projects. It has the advantages like condensed and easy to understand. But for the particularly complex projects, it shows the disadvantages that it cannot represent the relationship between the various tasks and the key point of completion of the plan in the progress schedule. So network planning method is more used nowadays. This is a method constitutes arrows from left to right according to the sequence and flow direction of the work process. With network planning method the construction management staff can easily find the key point and focus on it. During execution it can predict the impact of changes on duration and subsequent work in order to take timely countermeasures.

Currently there are some existing optimization methods for construction scheduling. Some softwares like Primavera, Microsoft Project, etc. are widely used.

Primavera is a project plan management software. Primavera is a powerful, integral and easy-to-use solution which includes prioritizing, planning, management, and execution of project, program and project portfolio.(Jian, C., 2008) Primavera can help to make better portfolio management decisions, evaluate project risks and returns, determine the resources and skills required to complete the work. As a first-class solution, Primavera has the execution and control capabilities of finishing the delivery of the project within specified time, budget, quality and scope of design. Primavera is involved in the fields of project management including: scope management, schedule management, cost management, resource management, risk management, and communication management.(Li, H., 2011)

Microsoft Project (or MSP) is a project management software program developed and sold by Microsoft. This software is designed to assist the project manager to develop plan, assign resources to tasks, track progress, manage budgets and analyze workload. The application can generate the critical path schedule, and the key chain can be made Gantt chart visualization. (Ding, W., 2007) Microsoft Project combines usability, powerful features and flexibility together perfectly. Microsoft Project provides a reliable project management tools, which helps construction management staff manage projects more efficiently. Microsoft Project can be integrated with the familiar Microsoft Office system programs, which can help construction management staff stay informed, control project work, schedules, and finances, maintain close cooperation with project working group, and improve the efficiency. (Lai, Z., 2008)

2.4. Applications of optimized design with genetic algorithms and quantum genetic algorithms

Genetic algorithms have been successfully applied to reliability optimization, flow shop scheduling, job shop scheduling, machine scheduling, equipment layout, image processing, and data mining in recent years. The research of quantum genetic algorithms is still in its infancy, and thus its related research is confined to limited aspects. (Yang and Zhuang, 2003) The theoretical applications are also more than the practical applications.

In a theoretical application, Han K H used the genetic quantum algorithm solving the 0-1 knapsack problem and verified the efficiency of the algorithm. 100, 250 and 500 were used as the standard data of objects in the experiment, and optimization solutions are obtained by applying genetic quantum algorithm.(Han, 2000)

LI B, Zhuang Z used the quantum genetic algorithm for function optimization. De Jong's unimodal function and Rosenbrock's multimodal function optimization were selected to optimize by quantum genetic algorithm. The result was significantly better than the result of conventional genetic algorithm and genetic quantum algorithm.(Li and Zhuang, 2002)

Li B applied quantum genetic algorithm to financial information data mining solving frequent pattern discovery problem in time series. The results were better than conventional genetic algorithm, niche genetic algorithm and genetic quantum algorithm.(Li, 2001)

Yang J, Zhuang Z combined quantum genetic algorithm and multi-Universe parallel quantum genetic algorithm to independent component analysis algorithm, and proposed a new blind source separation algorithm based on quantum genetic algorithm and multi-universe parallel quantum genetic algorithm. The simulation results showed that the computing efficiency of quantum genetic algorithm and multi-universe parallel quantum genetic algorithm and multi-universe parallel quantum genetic algorithm and multi-universe parallel quantum genetic algorithm. The simulation results showed that the computing efficiency of quantum genetic algorithm and multi-universe parallel quantum genetic algorithm is 5 to 15 times higher than that of conventional genetic algorithms.(Yang and Zhuang, 2003)

Genetic algorithms and quantum genetic algorithms also got a number of applications in industrial production.

In the field of industrial process optimization simulation the quantum genetic algorithm is applied. In the application of supercritical water oxidation technology to treat organic wastewater, Zhou C and Qian F gave an improved quantum genetic algorithm which can be used to estimate the kinetic parameters effectively in the optimization of the objective function with the presence of more than one kinetic parameter. Removal efficiency is the most important indicator in the application of supercritical water oxidation technology to treat organic wastewater. It is affected by the reaction temperature, pressure, residence

time, the amount of oxidant and catalyst factors. Accurate estimation of the kinetics parameters can thus accurately calculate the impact of various factors on the removal rate, and thus lay the foundation for the design and optimization of the industrial unit. (Zhou and Qian, 2008)

In chemical production, due to the precision of measuring instruments, measurement methods, and environmental impact, the actual on-site measurement data are unable to meet the theoretical material balance and energy balance constraints, so we need data correction to weed out the error in the measurement data. In data correction, the data classification and data coordination require the equation derivation or matrix conversion method, the calculation process is complex and the traditional method is prone to error. Guo J applied an improved quantum genetic algorithm to data correction, and with the simulation study of the flue gas system data correction and the distillation process data correction, that the feasibility of the program was indicated.(Guo, 2011)

In sustainable use of water resources evaluation, Zhao X, Li Z, and Ding J used real-coded chaotic quantum genetic algorithm for parameter optimization in regional sustainable use of the water resources evaluation model, and used the optimized model to make evaluations for regional water resources sustainable use. Comparing the results of evaluation of the measured data of the 12 regions in China with the results of other evaluation methods, the model has practicality and feasibility.(Zhao, Li, et al., 2007)

Improved quantum genetic algorithm-based parameter tuning method for PID controller design is also an application of quantum genetic algorithm. Due to the simple principle, easy concepts to understand, easy to implement and good robustness, the PID controller meets the general requirements of the industrial process and has been widely used in industrial control systems. The core issue of the PID control is PID parameters (proportional coefficient, integral time, derivative time). Zeng C, Zhao X introduced quantum crossover, quantum variation and groups cataclysm operation in the basis of quantum genetic algorithm, proposed an improved quantum genetic algorithm. The PID parameter tuning method based on improved quantum genetic algorithm transform the PID controller parameter tuning into a parameter optimization problem. Parameter tuning was achieved through the evolutionary computation of improved quantum genetic algorithm. The comparison of the simulation results with other parameters optimization methods shows that this method can get better quality control. The simulation results also demonstrate the feasibility of this method.(Zeng and Zhao, 2009)

In the civil engineering industry, the genetic algorithms are used in the diagnosis of structural damage, and achieved some results, which we describe later.

The dynamical method of structural damage diagnosis is based on the following inferences: there is a clear correspondence between dynamic parameters of the structure and stiffness, quality and the material constitutive characteristics. Catch the dynamic parameters of the structure by vibration test method then the work state of the structure

can be deduced.(Yi and Liu, 2001) Using genetic algorithms in damage diagnosis, take the measured structural free vibration frequencies and mode shapes as the basis, take the reduction ratio of a modulus of elasticity of the respective units of the structure as design variables, and change damage diagnosis from a structure parameter identification problem to a problem which only needs to conduct vibration analysis and genetic algorithm.(Li, W. and Chen, C., 2005) Genetic algorithm finds the optimal results with its unique way of thinking. The damage diagnosis optimization method with genetic algorithm, with not much information from test, not only can quickly find the damaged parts and can accurately simulate the extent of damage, even the optimization capability of genetic algorithm will not be affected when the mode may be lost.(Yi and Liu, 2001)

YI W, Liu X proposed improved genetic algorithm which is proved can be effectively applied to the field of damage diagnosis. Compared with the neural network, it does not require training samples, especially for large and complex structure without a lot of training samples. And the algorithm can identify the damage location and extent of damage of fixed end beams, continuous beams and frame structure, rather than some methods which must be indicated to the location of the injury.(Yi and Liu, 2001)

Li W, Chen C applied a genetic algorithm combined with sensitivity adjustment operation to structural damage diagnosis. Compared with simple genetic algorithm, genetic algorithm combined with sensitivity adjustment can greatly reduce the genetic iteration algebra, thereby reduce the computation time and improve the computational efficiency, and has a higher accuracy.(Li, W. and Chen, C., 2005)

Cheng X, Wang Y, Wang X took the element stiffness reduction factor as the identified parameters, took the frequencies and mode shapes as objective function, and calculated the reduction factor with genetic algorithms. And the effectiveness of recognition on the pile damage had been verified by example computation.(Cheng, Wang, et al., 2008)

Zhang W, Liu J converted structural damage diagnosis problem to the optimization problem based on offshore platform measured natural frequencies and mode shapes, and used genetic algorithms to deal with them. Numerical simulation and physical model experimental results both showed that the method can accurately diagnose structural damage of offshore jacket platform, improve the robustness of the evolutionary search, and improve the reliability of offshore platform structural damage diagnosis.(Zhang and Liu, 2011)

But there are also limitations to genetic algorithms in this area. Practice has proved that when the number of design variables is more than 20, the efficiency of simple genetic algorithm may be low due to a large design space need to deal with.(Yi and Liu, 2001) On the other hand, the genetic algorithm works in the way of groups and generations, the fitness value of each individual in each generation need to be calculated first in order to genetically manipulate to produce offsprings. In the field of civil engineering, the structural analysis program of calculating fitness value is more complex, the time used in the

analysis process is relatively long, causing the larger the population size, the more cost of time and the slower the rate of evolution. When the population size reaches a certain extent, the genetic algorithm runs too slow and loses the original superiority. So, in addition to the groups downsizing and reducing evolution algebra, improve the speed of convergence of the genetic algorithm is the key.(Yi and Liu, 2001) Quantum genetic algorithm has corresponding advantages, such as the population size is small, fast convergence speed, short computing time and better optimization ability. Therefore, quantum genetic algorithm provides the possibility for further solving the problem of structural damage diagnosis.

There are also some progresses in the application of genetic algorithm in the construction aspects, mainly in hydraulic engineering optimization.

Water conservancy project is a complex system engineering, global management of water conservancy projects needs to follow certain steps and procedures, and one of the main tasks of the management is schedule control. In project management, scientific and reasonable arrangement of the schedule and control of the progress of the construction is the important factor of ensuring the project schedule, guality and cost. In addition to schedule control, there are some other restrictions need to meet such as resource. The resource-constrained resource arrangements problem is an NP-Hard problem. Its purpose is to seek a planning program which can result in the shortest period and also meet the requirements of resource constraints. With mathematical methods when the network diagram of the process is increased, the times of calculation required will grow in accordance with the series level. Genetic algorithm is less restrictive for the problem itself. The objective function and the constraints of the problem need to be computable rather than differentiable or continuous. Meanwhile, genetic algorithm can always search throughout the entire solution space and is able to find near-global optimal solution, so it has a wide range of applications in the network planning optimization. There is certain superiority to apply genetic algorithm in optimize water conservancy project construction schedule control analysis with limited resources.(Wang, 2008)

Wang A applied genetic algorithm to solving the construction scheduling optimization problem of water conservancy projects with limited resources. He also applied his designed "limited resources, the shortest period optimization" mathematical model to optimize Huaihe Linhuaigang flood control project construction to seek the balance between the duration and cost. According to the principle of input parameters and the actual situation of selected problems, 3 sets of input parameters and 3 sets of optimized programs are chosen. Through the comparison of the optimization results, the optimal solution in the case of constant investment and other resources will shorten the duration from 232 months to 217.2months, which means compression durations of 6.4% (14.8months). For the entire project, the duration at least can be shortened by 3.6 months, accounting for 6% of the 60 months.(Wang, 2008)

2.5. Conceptual framework



Figure 3 Conceptual structure

3. Hypothesis

3.1. Theoretical basis and foundation

Due to the simulation of survival of the fittest in natural selection, the genetic algorithm has strong self-organizing and adaptive ability, intelligence, robustness, system optimization, etc. These enable that genetic algorithms are widely used in various areas like machine learning, artificial intelligence, and economic forecasts. In continuous integration and development process, the genetic algorithm also has extensive and far-reaching applications in civil engineering like structural damage diagnosis and process control.

However, despite the genetic algorithms show great advantages in solving problems, there are also limitations like large number of iterations and slow rate of convergence.

In combinatorial optimization problems there are various constraints which the feasible solution must satisfy. As a result, using traditional genetic operators such as crossover, variation may no longer be a feasible solution. And in solving process due to various restrictions, cross and other operators are likely to fall into local optimization.(Ma and Wang, 2005)

When the number of design variables is larger, the design space which needs to deal with will be correspondingly larger, and then the simple genetic algorithm can be inefficient. On the other hand, in the field of civil engineering, structural analysis program which is used to calculate each individual's fitness is more complicated. When the population size is relatively large, the fitness value of each individual in each generation must be calculated and then generate offsprings, this will make the cost of the time is too much and the speed of evolution is too slow. When population size reaches a certain extent, the genetic algorithm will run too slow and lose the original advantage. Ways to solve this problem are groups downsizing, reducing evolution algebra, and the key point is to improve the speed of convergence of the genetic algorithm.(Yi and Liu, 2001)

At this point, quantum genetic algorithm shows the possibilities to solve these limitations because it has corresponding advantages, such as the small population size, fast convergence speed, short computing time and better optimization ability. Quantum genetic algorithm is a product of the combination of quantum computation and genetic algorithms. In theory, that any problems that can be solved by genetic algorithm can also be investigated by quantum genetic algorithm. (Yang and Zhuang, 2003) So it can be expected that quantum genetic algorithm can also be applied in the fields in which genetic algorithm already applied, and because quantum genetic algorithm has better population

diversity and better computing parallelism, it has the possibility to make better optimization result.

According to the literature study, quantum genetic algorithms have already been used in industrialized use, for parameter optimization, combinatorial optimization, multi-objective optimization, etc. In these areas of application, QGA shows strong ability and advantages to solve problems. Quantum genetic algorithm can deal with problems with small population size, have fast convergence speed, short computing time and better optimization ability. And because quantum genetic algorithms have better population diversity and better computing parallelism, they offer the possibility to make better optimization result. So quantum genetic algorithm is chosen to apply in this research for the optimal design of construction scheduling.

Construction scheduling is often affected by multiple constraints. Therefore, optimizations of multiple objectives need to be met in the construction scheduling optimization design. The main two are the dual constraints of time and human resources. According to the above, in the optimal design of the construction scheduling, quantum genetic algorithm can be used for optimized design, to realize construction scheduling optimization design under the condition of the human resource constraint.

3.2. AQGA

We assume the existence of an algorithm called A quantum genetic algorithm (AQGA). This algorithm is an improved quantum genetic algorithm and is designed to solve the optimization problem under the conditions of multiple constraints. In this research, it is used for construction scheduling optimization design with the constraints of time and human resource.

We take a null hypothesis for this research: AQGA cannot help to improve the optimization design in civil engineering construction scheduling.

3.3. Working mechanics

3.3.1. Qubit encoding

In quantum genetic algorithm, a chromosome is characterized by qubits. What a qubit expresses is no longer determined, but it contains all the information. A qubit can be in the

state of "0", "1" or their superposition state. A chromosome of n qubits can expresses 2^n states. If a chromosome consists of n genes and a gene consists of k qubits, the chromosome is expressed as:

 $q_{j}^{t} = \begin{bmatrix} \alpha_{11}^{t} \\ \beta_{11}^{t} \\ \beta_{12}^{t} \end{bmatrix} \cdots \begin{bmatrix} \alpha_{1k}^{t} \\ \alpha_{1k}^{t} \\ \beta_{21}^{t} \end{bmatrix} \begin{bmatrix} \alpha_{22}^{t} \\ \alpha_{22}^{t} \\ \beta_{22}^{t} \end{bmatrix} \cdots \begin{bmatrix} \alpha_{2k}^{t} \\ \alpha_{2k}^{t} \\ \cdots \\ \beta_{2k}^{t} \end{bmatrix} \cdots \begin{bmatrix} \alpha_{n1}^{t} \\ \alpha_{n2}^{t} \\ \beta_{n2}^{t} \end{bmatrix} \cdots \begin{bmatrix} \alpha_{nk}^{t} \\ \beta_{nk}^{t} \end{bmatrix}$

In the formula, t represents the chromosome evolution algebraic, q_j^t represents the j-th individual chromosome of generation t.

Qubit encoding allows a chromosome to realize simultaneous expression of multiple superpositions. Qubit encoded chromosome expresses the probability distribution of the solution in solution space.

3.3.2. Decoding

Make a measurement for the qubit chromosomes and convert it into 0-1 binary strings.

3.3.3. Quantum rotation gate

In general, the quantum chromosome completes qubit update through quantum rotation gate, the update process is as follows:

$$\begin{bmatrix} \alpha'_i \\ \beta'_i \end{bmatrix} = U_i \times \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix} \times \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} \ .$$

In the formula, θ_i is the rotation angle, and its size and direction determine the performance of the algorithm. The rotation angle θ_i is determined by:

$$\theta_i = \Delta \theta_i \times \mathbf{s}(\alpha_i, \beta_i)$$

The adjustment strategy is shown in the following table: (Wang, Wu, et al., 2005)

x _i	b _i	$\mathbf{f}(\mathbf{x}) < f(b)$	$\Delta \theta_i$	α_i, β_i			
				$\alpha_i \beta_i > 0$	$\alpha_i \beta_i > 0$	$\alpha_i = 0$	$\beta_i = 0$
0	0	False	0	0	0	0	0
0	0	True	0	0	0	0	0
0	1	False	0	0	0	0	0
0	1	True	0.05π	-1	+1	±1	0
1	0	False	0.01π	-1	+1	±1	0
1	0	True	0.025π	+1	-1	0	±1
1	1	False	0.005π	+1	-1	0	±1
1	1	True	0.025π	+1	-1	0	±1

Table 1 Rotation angle selection strategy

In the table, x_i indicates corresponding binary bit in the i-th quantum bits of current chromosome x, b_i indicates corresponding binary bit in the i-th quantum bits of currently best individual chromosome b. f (x) indicates the fitness value of current chromosome, f (b) represents the fitness value of the current best individual. $\Delta \theta_i$ and $s(\alpha_i, \beta_i)$ respectively ensures that the size and direction of the rotation angle are correct.

The figure below illustrates the structure of the quantum rotation gate.



Figure 4 Quantum rotation gate diagram (Neto, De Andrade Bernert, et al., 2011)

3.3.4. Operator design

3.3.4.1. Quantum catastrophe

Quantum genetic algorithm easily falls into local optimum. Through the analysis of quantum genetic algorithm, it is found that if the best individual of the previous generation is local extremum, i.e., when the best individual doesn't change in successive generations, cataclysm operations need to be taken to add a larger disturbance to the populations in the evolutionary process. That can help them to be away from local extremum and start a new search.(Yang, Liu, et al., 2004) Set the cataclysm probability as P_z . When the best individual does not change for successive generations, keep the best individual in the population as the first chromosome of next generation. For other individuals, select and replace single qubit according to the catastrophe probability P_z or change the probability amplitude of qubit gene throughout the quantum. Of course, the other individuals can also be rebuilt.(Wang, Wu, et al., 2005)

3.3.4.2. Quantum crossover

Crossover operation can help achieve the structural information exchange between individuals. Set a crossover probability, randomly select certain individuals from the population to reorder and make them involved in crossover operation to complete the exchange of chromosome structure information.

3.3.4.3. Quantum mutation

The main role of quantum mutation is to slightly disrupt the evolutionary status of some individuals in the current population and improve the local search capabilities. Choose the quantum mutation probability P_e , select a quantum bit or a part qubit gene, and realize the mutation through quantum NOT gate.(Xiong, Chen, et al., 2004)

3.4. Workflow of AQGA

Step1 Establish initial population

If a chromosome consists of n genes and a gene consists of k qubits, the chromosome is expressed as:

$$q_{j}^{t} = \begin{bmatrix} \alpha_{11}^{t} \\ \beta_{11}^{t} \\ \beta_{12}^{t} \end{bmatrix} \overset{\alpha_{1k}^{t}}{\underset{\beta_{1k}^{t}}{\overset{\alpha_{21}^{t}}{\beta_{21}^{t}}}} \overset{\alpha_{21}^{t} \\ \beta_{21}^{t} \\ \beta_{22}^{t} \end{bmatrix} \overset{\alpha_{2k}^{t}}{\underset{\beta_{2k}^{t}}{\overset{\alpha_{2k}^{t}}{\beta_{21}^{t}}}} \overset{\alpha_{n1}^{t} \\ \overset{\alpha_{n1}^{t}}{\underset{\beta_{n2}^{t}}{\overset{\alpha_{n2}^{t}}{\beta_{n2}^{t}}}} \overset{\alpha_{nk}^{t} \\ \overset{\alpha_{nk}^{t}}{\underset{\beta_{nk}^{t}}{\overset{\alpha_{nk}^{t}}{\beta_{n2}^{t}}}} \end{bmatrix}$$

Each qubit (α_i, β_i) on all chromosomes is initialized to $(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})^T$, that indicates that a chromosome expresses the equiprobable superposition of its all possible states.

Step2 Measuring

Measure all the individuals of the initial populations and get the binary string $R(t) = \{\alpha_1^t, \alpha_2^t, \dots, \alpha_n^t\}$.

Step3 Evaluation

Determine a fitness function and make evaluation for each individual of the R (t). Retain the best individual in contemporary. Determine whether the termination condition is met, if it is met then stop algorithm, or else the following operations continue.

Step4 update with quantum rotation gate

Update the populations with quantum rotation gate U(t), which means for every qubit of quantum chromosome run:

$$\begin{bmatrix} \alpha'_i \\ \beta'_i \end{bmatrix} = U_i \times \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix} \times \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} \ .$$

Step5 Quantum catastrophe

If the best individual of successive generations does not change, make the catastrophic operation.

Step6 Quantum crossover and quantum mutation

Act crossover operator and mutation operator on the quantum chromosome to update populations.

Step7 Make t = t + 1, and start circulation.

4. Case study

In this case of the research of application of quantum genetic algorithm in civil engineering, construction scheduling is taken as an example. Some necessary simplifications will be made. As the growing trend of integration of the architectural design and construction, unit design and construction are more and more used. Units are some parts of the whole projects. They have same structure, or same construction process, or repetitive. Based on these characteristics, an analogy can be done between the unit construction scheduling and the flow-shop production scheduling. Through the analogy between flow-shop production scheduling, to integrate the application of quantum genetic algorithm into unit construction scheduling, and realize the unit construction scheduling optimization design.

4.1. Background

Flow-shop scheduling means that for a decomposable work, with the premise of meeting the constraints as much as possible, to achieve some performance indicators optimization through issuing production orders, arrangement of components and operating, choosing resources, and arranging processing time and processing order. The constraints can be delivery time, methods, resources, etc. and the performance indicators can be production cycle, production costs, etc. (Yu, Zhang, et al., 2009)

Flow-shop scheduling refers to that all the workpieces have the consistent processing order on all the same devices. Flow-Shop Scheduling Problem (FSSP) is an important class of problems frequently encountered in the production process, and is a simplified model of the actual assembly line production scheduling problem. FSSP means workpieces have consistent processing order on the machine; there is only one machine of the same kind of function; at the same time the machine can only machining one workpiece. Through a reasonable arrangement of the machining sequence, the aim is to achieve the optimal scheduling performance evaluation index.(Qu and Yang, 2007) Figure 5 describes the flow-shop scheduling problem.



Figure 5 Flow-shop scheduling

In the analogy of unit construction scheduling to flow-shop scheduling, the shared resources include: raw materials, equipment (processing equipment, maintenance equipment, transport equipment, etc.), energy, human resources, etc. The task is to compose the various units within a certain time. The optimization objectives can be the shortest construction time, a minimum of resource consumption or minimum human resources invested.

From the view of mathematical programming, scheduling problem can be expressed as an objective function optimization under certain equation or inequality constraints. In this case, the unit construction scheduling problem can be expressed as:

There are n units which need to be constructed by m workers. Every unit is divided into k processes. Each process can be processed by a number of different workers. At each moment, each worker can only construct one process of one unit. And only after the completion of the last procedure can the next process begin. The n units have the same construction sequence via the m workers. The goal of the problem is to strive for optimal construction sequence of the n units through the m workers. For this kind of problem usually the following assumptions are made:

(1) The construction order of every unit through the workers is 1, 2. ..., m;

(2) Each worker can only construct one unit at one moment;

(3) One unit cannot be simultaneously constructed by different workers;

(4) Units have the same processing order in one worker's construction.(Qu and Yang, 2007)

4.2. Modeling

After the research and comparison of flow-shop problems, in this case, the unit construction scheduling optimization problem is described as:

There are n units will be constructed by m workers. Each unit has the same order through

the workers. Each unit can only be operated once by each worker. At any one time each worker can only construct one unit. Only after the construction of the previous unit is completed by a worker, the next unit can begin the construction process by this worker. Every unit has an expected completion time (customer's requirements, subsequent step needed, etc.). If the unit is completed in the required completion period, there is no penalty. If there is tardiness then there are penalties. In addition, the human resource consumption is introduced. There is an estimated consumption for human resources. If there is too much human resources consumption there will be excessive consumption punishment of human resources. Construction process should not be interrupted. The goal is to determine the construction sequence, which can get the optimal result following this corresponding construction sequence.

By research and analogy to the mathematical model of the flow-shop production scheduling, and to simplify and modify it to adapt unit construction scheduling, in this case to establish the mathematical model as follows:

Min {P =
$$\sum_{i=1}^{n} [a_i max(t_{ij} - T_{ij}) + b_i max(h_{ij} - H_{ij})]$$
 }

Wherein, t_{ij} is actual completion time, T_{ij} is expected completion time. h_{ij} is actual human resources consumption, H_{ij} is expected human resources consumption. a_i is time tardiness penalty weight, b_i is the human resources over consumption penalty weight.

4.3. Optimization algorithm steps

Based on AQGA and flow-shop scheduling, the steps of the unit construction scheduling optimization are as follows:

Step1: Determine the model parameters

In the case of unit construction scheduling, the parameters included are: the number of the units which need to be constructed is N, the number of workers is M, crossover probability is P_c , mutation probability is P_e , cataclysm probability is P_z , the expected completion time is T_{ij} and the expected human resources consumption is H_{ij} .

Step2: Establish initial population

According to previous assumptions it is determined that the number of construction units is N, the number of workers is M. Then the quantum chromosome is as follows:

$$q_{j}^{t} = \begin{bmatrix} \alpha_{11}^{t} & \alpha_{12}^{t} \\ \beta_{11}^{t} & \beta_{12}^{t} \end{bmatrix} \cdots \begin{pmatrix} \alpha_{1k}^{t} & \alpha_{21}^{t} \\ \beta_{21}^{t} & \beta_{21}^{t} \end{bmatrix} \begin{pmatrix} \alpha_{22}^{t} & \alpha_{2k}^{t} \\ \beta_{22}^{t} & \beta_{22}^{t} \end{bmatrix} \cdots \begin{pmatrix} \alpha_{2k}^{t} \\ \beta_{2k}^{t} \end{bmatrix} \cdots \begin{pmatrix} \alpha_{n1}^{t} & \alpha_{n2}^{t} \\ \beta_{n2}^{t} & \beta_{n2}^{t} \end{bmatrix}$$

Wherein, q_j^t is the j-th chromosome of generation t. It contains n genes. Each gene having k quantum bits and k satisfies $2^{k-1} < N < 2^k$. Then a chromosome contains by N× k qubits and can express $2^{N \times k}$ states.

According to the actual size of the problem as well as the scheduling model parameters, it is determined that the population size is G. The chromosome's length is N × k. Each qubit on all chromosomes is initialized to $(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})^T$, that indicates that a chromosome expresses the equiprobable superposition of its all possible states.

Step3: Measuring and decoding

Measure all the chromosomes of the populations. By measuring, get the binary string R (t) of the corresponding measurement state of every quantum chromosome. Solving the problem of the construction sequence, the measured state binary string need to be further converted into the form of a random key. Decode all of the binary individuals of the R (t) and convert into decimal, and then the corresponding random key is got. Random key can be converted into the construction sequence of the unit. From this the construction sequence of the unit can be got.

Step4: Evaluation of all individuals of R (t)

By research and analogy to the mathematical model of the flow-shop production scheduling, and to simplify and modify it to adapt unit construction scheduling, in this case to establish the mathematical model as follows:

Min {P =
$$\sum_{i=1}^{n} [a_i max(t_{ij} - T_{ij}) + b_i max(h_{ij} - H_{ij})]$$
 }

Wherein, t_{ij} is actual completion time, h_{ij} is actual human resources consumption, a_i is time tardiness penalty weight, b_i is the human resources over consumption penalty weight.

After the establishment of a mathematical model, then the fitness function needs to be determined. In this unit construction scheduling problem, the objective function is the penalty value P of the unit. Set a sufficiently large value C_{max} , then fitness function is established as follows:

$F=C_{max}-P$

The larger value of F means the higher satisfaction, the smaller penalty value of construction scheduling, and the more optimal scheduling.

With the mathematical model and fitness function, start the construction according to the

construction sequence. Put various parameters into the mathematical model and calculated the corresponding fitness value for each construction sequence. Make evaluation of R (t), retain the best individual construction sequence, chromosome and fitness value and determine whether the termination condition is met. If met then output the optimal value, otherwise, continue to perform.

Step5: Update populations with quantum rotation gate

Update the populations with quantum rotation gate U(t), which means for every qubit of quantum chromosome run $\begin{bmatrix} \alpha'_i \\ \beta'_i \end{bmatrix} = U_i \times \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix}$, wherein $U_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix}$.

Step6: Run the operators

If the optimal individual does not change for successive generations, use catastrophic operator on chromosome. And then use crossover probability P_c selecting chromosome and make crossover operation to complete the exchange of information of chromosome. Then make mutation operations with the mutation operator to update populations, in order to improve the local search ability of the algorithm. Then make t = t +1 and step into the circulatory system.



Figure 6 QGA solving flowchart

4.4. Result

The theoretical basis of the case study is flow-shop scheduling. This chapter describes the basic concepts, basic characteristics and basic assumptions of the flow-shop scheduling. Unit construction is chosen to come up with the analogy of the flow-shop, and realized the optimized design using quantum genetic algorithm. Then a mathematical model of optimization design is established. Run the algorithm by putting unit construction scheduling into the AQGA which is established in the chapter 3 to make the optimized design. Through defining the parameters, establishment of the initial population, quantum chromosome encoding and decoding, determining the fitness function, updating the population with quantum rotation gate and running the operators, cycle calculation and optimization design are in progress as the workflow of improved quantum genetic algorithm. Finally the flowchart of unit construction optimized design with improved quantum genetic algorithm AQGA is given.

5. Conclusion and recommendation

In this research, the question whether a meaningful connection and combination of quantum computing and civil engineering can be achieved is raised. Through the connection and combination of quantum genetic algorithm and construction scheduling design, unit construction optimized design is realized through the improved quantum genetic algorithm.

5.1. Answer to research question

In the first part, the research question is presented as: How to apply quantum genetic algorithm to construction scheduling design? Hypothesis and the case study answer the research question through applying improved quantum genetic algorithm to construction scheduling design. In the case study, unit construction scheduling is taken as a specific example to demonstrate the application of optimal design in construction scheduling with quantum genetic algorithm.

For improving the hypothesis, due to the limitations it is not possible to do the simulation so there is no real data about the improvement of the optimized design for construction scheduling with quantum genetic algorithm. However as an achievement, the unit construction scheduling optimize problem is expressed by quantum computing language as presented in this research.

5.2. Achievements

Quantum genetic algorithm is a new optimization algorithm developed rapidly in the last decade. It uses quantum bit encoding, which means a chromosome can express superposition of multiple states. It has better diversity of population, and the population size can be very small without affecting the performance of the algorithm. The population is updated by quantum gates. Quantum genetic algorithm has good global search capability, the fewer number of iterations, the higher search efficiency and more broad applicability. In this research unit construction scheduling is selected and analogized with flow-shop scheduling problem as the research object. On the basis of the review and the sum up of the origin, development and improvement of quantum genetic algorithm, and also on the basis of detailed research and analysis of solving the unit construction scheduling problem with quantum genetic algorithm, in this research the following aspects are completed:

- (1) The introduction and analysis of genetic algorithms and quantum genetic algorithms are the starting points of the research. Quantum genetic algorithms are superior to the traditional algorithms even the genetic ones because QGA can realize small population size, fewer iterations, short computation time and strong global optimization ability. The construction scheduling is also introduced.
- (2) Through a large number of research and analysis on existing applications with genetic algorithms and quantum genetic algorithms, including theoretical applications, industrial applications, combinatorial optimization, multi-objective optimization, etc., we find the entry point. The unit construction scheduling is selected to be analogized with flow-shop scheduling with the aim to solve the optimized design with quantum genetic algorithm.
- (3) Hypothesis to solve construction scheduling optimization design is proposed-- the improved quantum genetic algorithm AQGA. Qubit encoding and updating populations by quantum rotation gate are analyzed. Several operators and the running steps of the algorithm and are given.
- (4) Take the unit construction scheduling as a case, apply the improved quantum genetic algorithm AQGA to optimize the design problem of solving unit construction scheduling. A mathematical model is established. Through defining parameters, establishment of the initial population, quantum chromosome encoding and decoding, determining the fitness function, updating the population with quantum gate and running the operators, cycle calculation and optimization design are realized with the workflow of improved quantum genetic algorithm. The flowchart of solving unit construction scheduling optimized design with improved quantum genetic algorithm AQGA is given at the end of the case study.

5.3. Limitations

As there are some constraints and limitations in the study and research, there are some issues to be further improved and perfected. For example:

(1) A lot of things are simplified and idealized. In the case study there are some simplified and idealized assumptions. For example, most of time the unit construction is a part of the project, like facade unit or floor unit. The actual project will be more complex. In addition, in the flow-shop scheduling problem the workpieces have the same process order, and for the workpiece once you start processing it can not be terminated. In actual construction there can be some appropriate adjustments. In the future more developed algorithms which will be more in line with the actual project and can solve more complex projects are expected. (2) By practical limitations the realistic simulation can not be realized because there is no existing detailed algorithm and no quantum computer to run the algorithm. The improvement of the optimized design for construction scheduling with quantum genetic algorithm can not be confirmed with data.

5.4. Future research

For the future research, I hope this can be a starting point for future cooperation of civil engineering and quantum computing. And some people really can write a specific and detailed algorithm for construction scheduling, and even more in other topics in civil engineering, like structure design, BIM, etc. And I really hope this report can be something useful, if any expert of quantum computing want to create a real algorithm to solve the construction scheduling optimized problem, this report can be used as a reference.

And it is also can be expected that unit can be not only one part of the project like unit facade or unit floor. More integrated skyscrapers may be created and constructed all by units. Then this research will be more useful in dealing with unit construction scheduling of more complexity with the powerful capabilities of quantum computing and quantum genetic algorithm.

All in all, as a powerful tool, I urgently hope quantum computing can be applied in civil engineering. The cooperation of civil engineering and quantum computing can be expected. More cooperation can promote more development and encourage more people to be involved in the research in this field. This may help the perfect and detailed algorithm for solving construction scheduling optimized problem exist earlier. And more algorithms in more aspects of civil engineering can also be expected. Quantum computing is a mysterious and powerful new world and it must be able to promote the development of civil engineering for a big step.

Nomenclature

- NP problem. NP problem means non-deterministic polynomial problem, which is the problem which can be solved with non-deterministic machine in polynomial time.
- Genetic Algorithm. Genetic algorithm is a search algorithm used to solve optimization in computational mathematics and is developed based on some phenomena in evolutionary biology including genetic, mutation, natural selection and hybridization.
- Quantum Genetic Algorithm. Quantum genetic algorithm is a newly developed optimization method based on the combination of quantum computation and genetic algorithms.
- AQGA. AQGA is an improved quantum genetic algorithm which is designed to solve the optimization problem under the conditions of multiple constraints in this research.
- Flow-Shop Scheduling. Flow-Shop Scheduling is a simplified model of the actual assembly line production scheduling in which all the workpieces have the consistent processing order on all the same devices.
- Quantum gate. Quantum gate is a quantum circuit which has basic operation on a small number of qubits
- Quantum NOT gate. Quantum NOT gate acts on a qubit and it can exchange the probability amplitude of I0> and I1>, which means I0> is replaced by I1> and I1> is replaced by I0>.
- Quantum rotation gate. Quantum rotation gate is expressed with matrix as: $U = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix}$ The update operation is achieved through the adjustment strategy of θ_i .

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Appendix 1 Quantum and Quantum Mechanics

The word "quantum" comes from the Latin (quantus), meaning "how much". In the microscopic field, the changes of some physical quantities are expressed as "jump" in the smallest unit rather than continuous. This smallest basic unit is called quantum.

Quantum Mechanics is a branch of physics which studies the laws of motion of microscopic particles. It includes the basic theory study of atoms, molecules, condensed matter, and the structure and characteristics of nuclei and elementary particles. Quantum Mechanics and Relativistic together constitute the theoretical basis of modern physics. Quantum mechanics is not only one of the basic theories of modern physics, and has been widely used in many related disciplines and many modern technology. Many theories of physics are based on quantum mechanics, such as atomic physics, solid state physics, nuclear physics and particle physics.

Basic concept:

- Quantum states
- Wave function
- State vector
- Wave-particle duality
- Quantum entanglement
- Quantum Measurement

Important theoretical

- Pauli Exclusion Principle
- Ehrenfest theorem
- Superposition principle
- Quantum tunneling effect
- Uncertainty principle (Zhang, 2002)

Appendix 2 Quantum Computing

Quantum computing is a new computing based on the theory of quantum mechanics. The principles and characteristics of quantum produce huge computing power. Two-registers in ordinary computer can only stores one of the four binary numbers (00, 01, 10, 11) at a time. But in Quantum computer, the two quantum bit (qubit) register can store the four numbers at the same times because each qubit can represent two values. If there are more qubits, computing power will be improved exponentially.

A 2-1 Qubit

A quantum bit (qubit) is the cornerstone of the theory of quantum computing. In a conventional computer, a bit of the binary is used to represent the information unit, which is either in the "0" state, or in the "1" state. In the binary quantum computers, information units are called quantum bits. In addition to the "0" state or the "1" state, quantum bits can also be in a superposition state.



Figure 7 A qubit superposition state diagram: Bloch sphere (Zhang, T., 2012)

Superposition state is any linear superposition of the "0" state and the "1" state. It may be a "0" state and also may be a "1" state, the states of "0" and "1" exist with a certain probability respectively at the same time, while showing a state "0" or "1" state by measurement or by interacting with other objects. Any two-state quantum system can be used to achieve a quantum bit.

A 2-2 Quantum gates

Quantum NOT gate and quantum rotation gate have been introduced in chapter 2.2, here are several other commonly used quantum gates.

Quantum Z gate can be expressed in matrix $Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$. When it acts on the qubit, it can maintain state $|0\rangle$ unchanged, state $|1\rangle$ reverse to $-|1\rangle$.

Quantum Y gate can be expressed in matrix $Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$. When it acts on the qubit, it can exchange the probability amplitude of $|0\rangle$ and $|1\rangle$. And the state $|0\rangle$ can be changed to $-|0\rangle$. (Wang, 2009)

Hadamard gate operates only on a single qubit. It can be express in matrix $H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$. This gate change the basic state $|0\rangle$ become $\frac{|0\rangle+|1\rangle}{\sqrt{2}}$, and $|1\rangle$ will become $\frac{|0\rangle-|1\rangle}{\sqrt{2}}$.(Yang and Zhuang, 2003)

A 2-3 Development Status of quantum computing

A 2-3-1 Proposal of the concept

The concept of Quantum Computing was first proposed by R. Landauer and C. Bennett from IBM in the 1970s. They mainly discussed the relationship between the free energy, information and reversibility in the calculation process. In the early 1980s, P. Benioff first proposed two-level quantum system can be used to simulate digital calculation. Later Feynman was also interested in this issue, and gave a speech at the First Conference on Physics of Computation in Massachusetts Institute of Technology in 1981, sketching out a vision to achieve the calculation of quantum phenomena. In 1985, D. Deutsch from the University of Oxford proposed the concept of quantum Turing machines. However, the Quantum Computing research above is mostly limited to explore the physical nature of the calculation and stay in a fairly abstract level with no further development of the algorithm.(Xia, 2001)

A 2-3-2 Medium-term development

In 1994, P. Shor, who is an applied mathematician, pointed out that compared to a conventional electronic calculator, quantum computing can be used to decompose a large integer into the product of the prime factors within a considerably shorter period of time. This conclusion opened a new phase for the development of Quantum Computing:

quantum algorithms, which are different from the traditional calculation rule, do have their practicality. Since then, new quantum algorithms have been successively proposed. One of the important topics for physicist is how to build a real quantum calculator to perform these quantum algorithms. Many quantum systems have all been proposed as infrastructure of quantum calculator, like photon polarization, cavity quantum electrodynamics (CQED), ion trap, NMR (nuclear magnetic resonance) and so on. In the current technology, ion trap and NMR are most feasible.(Xia, 2001)

A 2-3-3 Development prospects

Quantum computing may make the computing power of the computer much higher than today's computer, but there are still many obstacles. A problem for mass quantum computing is that it is difficult to improve the accuracy of desired quantum devices.

In early 2007, D-Wave, a Canadian quantum computing company, demonstrated the world's first commercial practical quantum computer "Orion". It is a special purpose machine which can solve the problems with quantum mechanics. After a lapse of four, D-Wave officially launched the world's first commercial quantum computer "D-Wave One". It uses a 128-qubit (quantum bit) processor, which is as four times as the previous prototype. Its theoretical computing speed has gone far beyond any existing super computer.

However, it can only handle specific tasks which have been optimized now. For common tasks it is still far away behind the traditional silicon processor. D-Wave One has very harsh requirements in cooling and it need full protection by liquid helium. And the current price of D-Wave One is up to 10 million dollars.(Qu, D., 2011)